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EFFECTS OF TIME AND METHOD OF TERMINATING ALFALFA STANDS ON GREENHOUSE GAS EMISSIONS, SOIL N SUPPLY, FERTILIZER N REQUIREMENTS AND CROP YIELD

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Effects of Time and Method of Terminating Alfalfa Stands on Greenhouse Gas Emissions, Soil N Supply, Fertilizer N Requirements and Crop Yield

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Abstract

A field experiment was conducted in a seven-year old alfalfa stand on a Gray Luvisol (Typic Cryoboralf) loam soil near Star City in north-eastern Saskatchewan to compare the influence of time and method of terminating alfalfa stands on yield, seed quality, N uptake, recovery of applied N and N fertilizer requirements for wheat and canola grown four years after stand termination. Soil mineral N (ammonium-N and nitrate-N), soil bulk density, total and light fraction organic C and N in soil, and nitrous oxide (N_2O) emissions were also measured. The treatments were a 3 x 3 x 4 factorial combination of three termination methods (tillage, herbicide, and herbicide + tillage), three termination times (after cut 1 and cut 2 in 2003, and in spring 2004) and four rates of N (0, 40, 80, and 120 kg N ha^{-1}) applied at seeding to wheat-canola rotation from 2004 to 2007. Soil nitrate-N in autumn 2003 and spring 2004 was higher in tilled or herbicide + tilled treatments than in the herbicide treatment and decreased with delay in termination. In the first crop year (2004), method and timing of termination significantly influenced all crop factors. Seed and straw yields of wheat grown on tilled and tilled + herbicide treatments were similar, both significantly greater than herbicide alone, due to greater content of soil available N in tillage treatments. Yields decreased with delay in termination time, except on the herbicide treatment where yields were highest for the spring termination. Seed and straw yield of wheat was similarly affected in 2006. Seed protein responded significantly to method and timing in 2004, and was higher on herbicide, particularly after cut 2, likely due to lower seed yield. Increased N application rate tended to increase protein for all years of the study. Canola oil concentration was inversely related to protein. Percent recovery of applied N in the seed decreased with increasing N rate for wheat (2004 and 2006). Percent recovery of applied N in canola straw decreased in 2005 but increased in 2007 with increasing N rate. Nitrogen application significantly affected all other factors in each year. In general, yield and N uptake in seed and straw, and protein concentration tended to increase with increasing N rate. Nitrogen application interacted with termination method in 2004 and 2006. A greater yield increase occurred on the herbicide compared to tillage and herbicide + tillage treatments from the first increments of N applied, with similar yield increase at the higher N rates. Timing of alfalfa termination and N application interacted significantly in 2004, with spring termination having the lowest yield when no fertilizer N was applied, but the highest yield when 120 kg N ha^{-1} was applied. Nitrous oxide emissions were generally low. The N_2O emissions from the herbicide treatment were lowest of all treatments in

2004, but highest in 2005. There were no treatment differences evident when cumulative 4-year N_2O-N losses were compared. Appropriate N fertilization was able to compensate for yield reductions due to delayed termination timing, but could not do so entirely for yield reductions on the herbicide compared to tillage or herbicide + tillage termination method. The amounts of TOC, TON, LFOC and LFON after four growing seasons were usually higher or tended to be higher under herbicide (no-till) treatment than under tillage treatment in the 0-5 cm soil layer, but the opposite was true in the 5-10 or 10-15 soil cm layers. The amount of TOC and TON was higher, and LFOM, LFOC and LFON tended to be higher in the 0-5 cm soil layer with N application. Overall, herbicide (no-till) and N fertilization had or tended to have positive effect on organic C and N, especially light fraction organic C and N. Soil bulk density increased with elimination of tillage but only in the 5-10 cm depth, and it is not considered to have a negative impact on root growth and crop yield.

Keywords: Aggregation; Alfalfa termination; Greenhouse gas; N uptake; Organic C and N; Protein concentration; Soil mineral N; Yield

Executive Summary

No-till reduces erosion, and improves structure, quality and health of soil, reduces potential for nitrate contamination of groundwater, and CO_2 (carbon dioxide) and N_2O (nitrous oxide) greenhouse gas emissions into the atmosphere, while also sustaining high crop production. Research is required to determine if no-till termination of alfalfa can improve synchronization between N release from alfalfa residues and its uptake by succeeding annual crops, thereby optimizing economic benefits and minimizing damage to the environment. A field experiment was conducted in a seven-year old alfalfa stand on a Gray Luvisol (Typic Cryoboralf) loam soil near Star City in northeastern Saskatchewan to compare the influence of time and method of terminating alfalfa stands on yield, seed quality, N uptake, recovery of applied N and N fertilizer requirements for wheat (*Triticum aestivum* L.) and canola (*Brassica napus* L.), soil mineral N (ammonium-N and nitrate-N), soil bulk density, total and light fraction organic C and N in soil, and nitrous oxide (N_2O) emissions. The treatments were a 3 x 3 x 4 factorial combination of three termination methods (tillage, herbicide, and herbicide + tillage), three termination times (after cut 1 and cut 2 in 2003, and in spring 2004) and four rates of N (0, 40, 80, and 120 kg N ha^{-1}) applied at seeding time to wheat-canola rotation

over four years from 2004 to 2007. Selected treatments were sampled for soil mineral N (ammonium-N and nitrate-N) on October 29, 2003 and May 11, 2004, for soil organic C and N in autumn 2007, and for N_2O gas emissions from early spring through summer to autumn in all years.

In the termination year, soil nitrate-N was higher in tilled or herbicide + tilled plots than in herbicide plots in autumn 2003 and decreased with delay in termination. In the first crop year (2004) after alfalfa stand termination, soil nitrate-N in spring 2004 was also higher in tilled or herbicide + tilled plots than in herbicide only plots, and decreased with delay in termination. Maximum seed yield and N uptake of wheat was produced from termination in spring in herbicide treatment, and from termination after cut 1 in the tillage or herbicide + tillage treatments. Delay in stand termination with tillage or herbicide + tillage decreased seed yield and N uptake, but the negative influence was much larger at 0 and 40 kg N ha^{-1} than at 80 and 120 kg N ha^{-1} rates. Spring was the best time for stand termination using herbicide, but herbicide method produced lower yield and N uptake than tillage or herbicide + tillage, particularly with termination after cut 1 and cut 2. The differences in seed yield and N uptake produced with different termination methods were relatively greater at lower than at higher N rates, and with earlier than later stand termination time. There was usually no significant increase in seed yield above 80 kg N ha^{-1} (except with herbicide in spring where it continued to increase up to 120 kg N ha^{-1} rate). Protein concentration increased, but recovery of applied N in seed decreased with increasing N rate. Protein concentration was highest with herbicide method and lowest with spring termination. The differences between termination times were much greater for herbicide than tillage and herbicide + tillage termination methods. Thousand seed weight (TSW) increased with increasing N rate, but decreased with delaying alfalfa termination time to the following spring. The TSW was higher with tillage termination method than herbicide alone. Recovery of applied N in seed for tillage or herbicide + tillage methods was in the order of termination in spring > termination after cut 2 > termination after cut 1 at all N rates. For the herbicide only method of termination, it was cut 1 > spring > cut 2 for 40 kg N ha^{-1} rate, and was spring > cut 1 > cut 2 for the 80 and 120 kg N ha^{-1} rates. Mean cumulative N_2O-N loss during 2004 ranged from 220 to 420 g N ha^{-1}. There were negligible N_2O emissions during the snow melt period likely due to dry conditions in previous autumn and limited snow cover in winter. The N_2O loss tended to be lower with termination after cut 1 than the other termination times. The N_2O emissions from tillage termination were significantly higher than termination by herbicide. Stand termination

by herbicide or delay in stand termination with tillage resulted in increased response of yield and N uptake to N fertilization, indicating reduced N supply from soil and alfalfa residues in these treatments. Seed and straw yield and N uptake showed nearly similar response to the stand termination methods and times as well as N fertilization. There was no significant effect of termination method, termination time and N rate on protein concentration in wheat seed.

In the second crop year (2005) after alfalfa termination, soil nitrate-N in spring 2005 was usually higher in herbicide than in tillage or herbicide + tillage treatments. There was little or no effect of termination time on soil nitrate-N. Seed yield, protein concentration and N uptake of canola increased, but oil concentration decreased with increasing rate of N application. There was no significant effect of termination time or method on seed yield and TSW, but in the zero-N treatment seed yield, protein concentration and N uptake tended to be higher and oil concentration tended to be lower with herbicide than tillage or herbicide + tillage methods. Oil concentration in seed increased, but protein concentration and N uptake in seed decreased with delay in termination. Oil concentration in seed was higher with tillage or herbicide + tillage termination methods, but the opposite was true for protein concentration and N uptake in seed. Recovery of applied N in seed for herbicide method of termination was in the order of cut 1 > cut 2 > spring termination time at the 40 and 120 kg N ha^{-1} rates. There was no consistent trend for tillage or herbicide + tillage termination methods. Mean cumulative N_2O-N loss during 2005 ranged from 330 and 730 g N ha^{-1}. The N_2O emissions during the snow melt period were substantially higher (representing 16 to 55% of the cumulative seasonal totals). The N_2O-N loss tended to decline with delay in termination. The N_2O emissions from tillage termination were lower than termination by herbicide. This is consistent with tillage producing a greater flush of microbial activity and nitrate release in the first year, and that diminished by the second year.

In the third crop year (2006) after alfalfa termination, seed yield and TSW of wheat increased with increasing N rate. There was no significant effect of termination time or method on seed yield, but in the zero-N treatment seed yield tended to be lower with herbicide method than tillage or herbicide + tillage method.

In the fourth crop year (2007) after alfalfa termination, N fertilization had a substantial effect on seed and straw yield of canola, with maximum seed yields usually at 120 kg N ha^{-1} rate and straw yields at 80 kg N ha^{-1} rate. Termination time had no effect on these parameters. Both seed and straw

yield were similar in herbicide alone (no-till), tillage and herbicide + tillage treatments, regardless of the rate of N fertilization. The patterns of yield, N uptake and recovery of applied N for straw to termination and N fertilizer treatments were generally similar to seed in all years.

Nitrous oxide emissions following termination of a seven-year old alfalfa stand were low. The timing of the stand termination had no influence on cumulative N_2O loss. The method of stand termination did have an influence on N_2O loss. The herbicide termination method had the lowest N_2O loss in the first year following termination, while tillage method had the highest loss. In the second year following termination the situation was reversed, essentially offsetting the differences in the first year. Thus, when considered on a cumulative basis over a three or four year period, N_2O loss was not greatly affected by method or timing of stand termination. Fertilizer application significantly increased N_2O emissions, with a fertilizer-induced emission coefficient of about 0.4% of applied N, based on one year of data.

The amounts of TOC, TON, LFOC and LFON after four growing seasons were usually higher or tended to be higher under herbicide (no-till) treatment than under tillage treatment in the 0-5 cm soil layer, but the opposite was true in the 5-10 or 10-15 cm soil layers. This resulted in non-significant effect of tillage on these parameters. The amount of TOC, TON, LFOM, LFOC and LFON tended to be higher in the 0-5 cm soil layer with N application. Alfalfa termination in spring had or tended to have lowest amount of LFOM, LFOC and LFON.

Soil bulk density was significantly decreased with N application, and increased with elimination of tillage, but only in the 5-10 cm depth. The increase in bulk density due to no-till is not considered to have detriment to root growth and crop yield

In summary, the findings indicate that in the first crop year after alfalfa stand termination, N fertilization can be used to compensate for the decline in yield due to a delay in alfalfa stand termination to the spring in which the annual crop is seeded. There was a delayed release of mineral N in herbicide termination treatments compared to tillage. Therefore, herbicide (no-till) termination may reduce the potential for nitrate-N loss to the environment in the first year if there is potential for large releases of nitrate, but may also require additional application of fertilizer N to maximize annual crop yield. The effect of termination method diminished in the second year (canola - 2005), small (but significant) impact in the third year (wheat - 2006), and disappeared completely in the fourth growing season (canola - 2007) following termination. It is possible that drought and/or dry

moisture conditions in the 2001, 2002, and also 2003 growing seasons may have limited N_2 fixation by alfalfa, and subsequently resulting in short-term residual effects on plant-available N in soil, and crop yield and N uptake in our study. The differences in the impact of termination methods on crop yield and N uptake between 2005 and 2006 could be due to slightly higher (but significant) soil nitrate-N under tillage than no-till (herbicide) treatment in 2006 compared to 2005. Also, these differences could be because of the type of crop species with different rooting system (i.e., long taproot for canola and relatively short fibrous roots for wheat, with different abilities to extract nutrients from surface and subsoil layers). The findings suggest that termination timing and method have limited influence on cumulative N_2O emission at this study site. Herbicide (no-till) and N fertilization had or tended to have positive effect on organic C and N amounts, especially light fraction organic C and N in the surface (0-5 cm) soil layer. Soil bulk density increased with elimination of tillage but only in the 5-10 cm depth, and it is not considered to have a negative impact on root growth and/or crop yield.

Technical Report

1. Introduction

In the Parkland region of western Canada, alfalfa is often grown for forage or seed production in rotations with annual crops. In a rotation, alfalfa reduces the input of N fertilizer for the succeeding annual crops while also improving seed yield and protein content (Baddarudin and Meyer, 1990; Zentner et al., 1990, 2001; Entz et al., 1995; Mohr et al., 1999). It also helps to reduce soil salinity (Agriculture Canada, 1991), soil erosion (Stinner and House, 1989) and weed populations (Dryden et al., 1983; Harvey and McNevin, 1990), and improve soil moisture by snow trapping (Cutforth et al., 2002), physical properties (Blackwell et al., 1990) and organic matter (Campbell et al., 1990). Therefore, the inclusion of alfalfa in cropping systems is particularly important in the Parkland region, where Gray Luvisol (Typic Cryoboralf) soils are inherently low in organic matter and pose surface crusting problems for crop emergence.

In northeastern Saskatchewan, alfalfa is grown on approximately 23,000 ha for the dehydrated alfalfa pellet market (Saskatchewan Agriculture, 2008), plus more areas grown under

seed production and hay. After about 3 years, the productivity of alfalfa stands tends to decline. Because of low productivity and infestation of weeds, about 20,000 ha of alfalfa are terminated every year. Entz et al. (1995) have reported that approximately 80% of the forage producers terminate alfalfa stands primarily by tillage using 5-7 tillage operations. However, termination of alfalfa stands by this method exposes the soil to erosion by wind and water, causes loss of soil moisture, and can also lead to deterioration of soil structure and crusting, resulting in poor seedling emergence and crop stands. This can also result in release of substantial amounts of nitrate-N from native soil organic N (Malhi and Nyborg, 1987), which is subjected to loss by leaching and denitrification (Malhi and Nyborg, 1983, 1986, 1987, 1990).

Because herbicides kill alfalfa effectively, no-tillage (NT) can be used as a feasible alternative to conventional (CT) tillage for alfalfa stand termination (Button, 1991; Allen and Entz, 1994) to establish crop stand (Wolf et al., 1985). In addition, no-till (herbicide) termination may improve soil moisture conservation and other properties, and reduce erosion and potential for nitrate contamination of groundwater, and CO_2 (carbon dioxide) and N_2O (nitrous oxide) greenhouse gas emissions into the atmosphere, while also sustaining high crop production (Aflakpui et al., 1994; Allen and Entz, 1994; Cutforth et al., 2002). Therefore, research is required to determine if no-till (herbicide) termination of alfalfa can improve the synchronization between N release from alfalfa residues and its uptake by succeeding annual crops, thereby optimizing economic benefits and minimizing damage to the environment.

Previous studies in western Canada have shown lower seed yield of wheat when alfalfa was terminated by herbicide rather than tillage, and also reduced N uptake of wheat by delaying termination until the following spring (Bullied et al., 1999; Mohr et al., 1999; Malhi et al., 2007). They attributed this to reduced rates of mineralization of organic N in soil treated with herbicide (no-till) compared to tilled soil. This suggests that crop yield in herbicide termination treatment can be improved by applying N fertilizer, when plant-available N is low in the soil. Information is lacking on the use of NT technique for termination of alfalfa stands under different N fertility regimes in this area. The objective of this study was to compare the influence of time and method of terminating alfalfa stands on crop yield, seed quality, N uptake, recovery of applied N and N fertilizer requirements for wheat (*Triticum aestivum* L.) and canola (*Brassica napus* L.), soil mineral N (ammonium-N and nitrate-N), soil bulk density, total and light fraction organic C and N in soil, and

N_2O emissions on a Gray Luvisol soil.

2. Materials and methods

The field experiment was conducted from 2003 to 2007 near Star City in northeastern Saskatchewan (52° 52′ N, 104° 20′ W). The soil at the site was a Gray Luvisol (Boralf) with loam texture, 3.1% organic matter and a pH of 6.6. Mean annual air temperature and precipitation in the area is 0.3°C and 410 mm, respectively (long-term average at AAFC Melfort Research Farm). Mean monthly precipitation and air temperature in May, June, July and August in 2003, 2004, 2005, 2006 and 2007 at the nearest Environment Canada Meteorologial Station (Melfort Research farm) are presented in **Table 1**. The long-term average at the nearest Environment Canada Meteorologial Station (Melfort Research Farm) in May, June, July and August (crop growing season) is 46, 66, 75 and 57 mm for precipitation and 10.8, 15.7, 17.4 and 16.4 °C for air temperature, respectively. Mean precipitation in the growing season (May through August) is about 244 mm for this area. The growing season precipitation at the experimental site was 290 mm in 2004, 372 mm in 2005, 220 mm in 2006 and 304 mm in 2007.

The 36 treatments replicated four times in a randomized complete block design included 3 x 3 x 4 factorial combinations of three methods of termination [herbicide (NT), tillage, and herbicide + tillage], three times of termination (after cut 1 and cut 2 in 2003, and in spring 2004) and four rates of N (0, 40, 80 and 120 kg N ha^{-1}). Herbicides used for termination were Lontrel + 2,4-D and Glyphosate + 2,4-D. Tillage and herbicide application dates for the three methods and three times of alfalfa termination are given in **Table 2.** Individual plots were 4 m x 15 m. The stand termination treatments were initiated on a seven-year old alfalfa stand (used for Dehy) in the summer of 2003. Blanket applications of phosphorus - P (30 kg P ha^{-1}), potassium - K (42 kg K ha^{-1}) and sulphur - S (17 kg S ha^{-1}) fertilizers were broadcast on all plots prior to tillage and sowing in spring of 2004. Nitrogen fertilizer was side-banded 2.5 cm away and 2.5 cm below seed rows of wheat and canola at sowing. The fertilizer source was urea for N, triple superphosphate for P, and potassium sulphate for K and S. The plots were seeded to annual crops in a rotation of wheat (*Triticum aestivum* L. cv. CPS 500PR) in 2004, canola (*Brassica napus* L. cv. InVigor 2573 - hybrid) in 2005, wheat (cv. AC Barrie) in 2006 and canola (cv. LL 5108 - hybrid) in 2007. Seed rate was 108 and 9 kg ha^{-1} and seeding depth was 4.4, and 1.9 cm for wheat, and canola, respectively. Each year the crop was seeded

in May with a ConservaPack drill equipped with knives in 22.5 cm rows. Appropriate herbicides were used in all plots for in-crop weed control.

At crop maturity, four 1-m length rows per plot were harvested for dry matter determination. The samples were thrashed to determine seed:straw ratios. Seed yield was determined by harvesting 5 rows in the centre of each plot using a combine. Seed yields in combination with seed:straw ratios from dry matter samples were used to calculate straw yields. Representative seed and straw samples (dried at 60°C) were finely ground and analyzed using CNS combustion analyzer for total N (TN) (AOAC, 1995). Total N uptake (kg N ha^{-1}) was calculated as: seed (or straw) yield in kg ha^{-1} x total N concentration (g N kg^{-1}) in seed (or straw) x 0.001. Protein concentration was calculated by multiplying the total N by 6.25 for canola, and by 5.70 for wheat (Williams et al., 1998). Seed weight was measured on 1000 seeds counted by using electronic counter, and hereafter referred as thousand seed weight (TSW).

In the autumn of 2003 (October 29) and 2007 (September 26-27), and spring of 2004 (May 11), 2005 (May 9), 2006 (May 11) and 2007 (May 10), selected treatments were sampled from the 0-15, 15-30 and 30-60 cm depths (three locations per plot using a 4 cm diameter coring tube) for nitrate-N (NO_3-N) and ammonium-N (NH_4-N). In the autumn of 2007, soil samples were collected from the 0-5, 5-10 and 10-15 cm depths (eight locations per plot using a 3 cm diameter coring tube) for total organic C (TOC) and N (TON) and light fraction organic matter LFOM), C (LFOC) and N (LFON). Bulk density of soil was determined by the core method (Culley, 1993). The samples were air dried at room temperature after removing coarse roots and easily detectable crop residues, and ground to pass through a 2-mm sieve. Sub-samples for the 0-5, 5-10 and 10-15 cm depths were pulverized in a vibrating-ball mill (Retsch, Type MM2, Brinkman Instruments Co., Toronto, Ontario). The method of Technicon Industrial Systems (1977) was used to determine TON in the soil. Light fraction organic matter (LFOM) was separated using a NaI solution of 1.7 Mg m^{-3} specific gravity, following the method described by Janzen et al. (1992) and modified by Izaurralde et al. (1998). The C and N in LFOM (LFOC, LFON) were measured by Dumas combustion using a Carlo Erba instrument (Model NA 1500, Carlo Erba Strumentazione, Italy). The NO_3-N and NH_4-N in soil were extracted using 1:5 soil:2M KCl solution (Keeny and Nelson, 1982) and their concentrations in extracts were measured with a Technicon Autoanalyzer II (Technicon Industrial Systems, 1973a, b).

Nitrous oxide emissions were measured between snow melt and late summer or autumn from the zero-N treatment on all alfalfa termination timing and method treatments in 2004, 2005 and 2006. In 2007, measurements on the herbicide + tillage treatment were discontinued and N_2O measurements on a second fertilizer-N rate (80 kg N ha^{-1}) treatment were added. Sampling was conducted on 20 sampling dates from April 13 to September 9 in 2004, 20 sampling dates from April 7 to October 14 in 2005, 23 sampling dates from April 20 to August 24 in 2006, and 15 sampling dates from April 15 to August 22 in 2007. Treatments were sampled using non-flow through, non-steady state soil chambers as described by Corre et al. (1996). Nitrous oxide flux was estimated from the concentration change in the chamber headspace over a 60 minute period. Samples were drawn from the headspace by fully filling disposable 20 ml polypropylene syringes. The entire gas sample was then injected into pre-evacuated 13 ml exetainer™ glass tubes for transport to the laboratory. The concentration of N_2O in the sample containers was determined using a gas chromatograph equipped with a ^{63}Ni electron capture detector. The calculated minimum detectable difference for the system was <10 ppbv. The N_2O flux was calculated from the rate of change in N_2O concentration over time assuming a linear increase. Time zero values were estimated using a method similar to that described by Anthony et al. (1995). A series of ambient air samples were collected at each sampling time. The mean of these samples was used as the time zero concentration. Cumulative estimates were calculated by interpolating between data points and integrating over time assuming a constant flux (Lemke et al., 1999).

The data on each parameter were analyzed for analysis of variance (ANOVA) using a factorial structure of the treatments (SAS Institute Inc., 2004). The ANOVA of collected data determined the main and interaction effects of termination method, termination time and N rate using GLM procedure in SAS. Least significant difference ($LSD_{0.05}$) was used to determine significant differences between treatment means. For each comparison, $LSD_{0.05}$, standard error of the mean (SEM) and significance level are reported. Significance of linear and quadratic effects of N rate for different parameters is presented in various tables.

3. Results and discussion

The standard error of the mean (SEM) and significance of ANOVA effects of termination method (M), termination time (T), N rate (N), and M x T, M x N, T x N and M x T x N interactions

on seed and straw yield, protein and/or oil concentration in seed, thousand seed weight (TSW), N uptake in seed and straw, and percent recovery of applied N in seed and straw in 2004, 2005, 2006 and 2007 are presented in **Table 3**.

In 2004, termination method, termination time, N rate and termination method x termination time interaction had a significant effect on seed and straw yield, protein concentration in seed, TSW, N uptake in seed and straw, and percent recovery of applied N in seed (**Table 3**). Interaction effect of termination method x N rate and termination time x N rate was significant for seed yield, N uptake and TSW. Interaction effect of termination method x termination time x N rate was significant for only seed yield and N uptake. The percent recovery of applied N in straw was affected by only termination method ($P < 0.10$) and termination time.

In 2005, N rate had a significant effect on canola seed and straw yield, protein and oil concentration in seed, N uptake in seed and straw, and percent recovery of applied N in straw (**Table 3**). There was a significant effect of termination method on oil concentration in seed, N uptake in straw and percent recovery of applied N in seed, and of termination time on protein and oil concentration and N uptake in seed, and percent recovery of applied N in straw. Interaction effect of termination time x N rate and termination method x termination time x N rate was significant only for straw yield at $P<0.10$.

In 2006, N rate had a significant effect on wheat seed and straw yield, protein concentration in seed, N uptake in seed and straw, and percent recovery of applied N in seed (**Table 3**). There was a significant effect of termination method on yield and N uptake of both seed and straw, and of termination time on protein concentration and N uptake in seed at $P<0.10$. Interaction effect of termination method x N rate was significant only for seed and straw yield. The percent recovery of applied N was significantly affected only by termination method x N rate for straw.

In 2007, N rate had significant effect on canola seed and straw yield, protein and oil concentration in seed, and N uptake and percent recovery of applied N in seed and straw (**Table 3**). There was a significant effect of termination method on TSW, N uptake in seed and straw, and percent recovery of applied N in straw. Termination time had no significant effect on any parameters. Interaction effect of termination method x termination time was significant for straw yield, protein and oil concentration in seed, TSW, N uptake in straw, and percent recovery of applied N in seed and straw mostly at $P<0.10$.

3.1. Immediate Effect of Alfalfa Termination on Soil Mineral N, Crop Yield, Seed Quality, N Uptake, Recovery of Applied N and Nitrous Oxide Emissions

3.1.1. Soil mineral N

In autumn 2003, concentration of nitrate-N in soil was higher in tilled or herbicide + tilled plots than the herbicide alone plots, and decreased with delay in termination (**Table 4**). Tillage effect on soil nitrate-N concentration was much more pronounced in the 0-15 cm depth, and there was no increase in soil nitrate-N in the 30-60 cm depth. There was little or no effect of termination method or time on soil ammonium-N concentration. In spring 2004 sampling, soil nitrate-N concentration was also higher with tillage and herbicide + tillage treatments than herbicide alone treatment (**Table 5**). Concentration of nitrate-N in soil decreased with delay in termination time, with very low nitrate-N concentration when alfalfa was terminated in spring compared to the other two termination times. Again, there was no treatment effect on soil ammonium-N in spring 2004. Similar to the present study, in a previous study in northeastern Saskatchewan, alfalfa termination by tillage increased spring soil nitrate-N over herbicide alone, and also termination after cut 1 had the highest levels of soil nitrate-N (Malhi et al., 2007). In that study, alfalfa termination time and method also had little effect on soil ammonium-N in spring. Other earlier studies have also shown lower accumulation of nitrate-N in soil when green manure crops were terminated by herbicides rather than tillage (Biederbeck and Slinkard, 1988; Sarrantonio and Scott, 1988). In other studies, researchers have reported greater soil nitrate-N levels when alfalfa residues were incorporated into soil compared to those left on the soil surface (Biederbeck and Slinkard, 1988; Mohr et al., 1999). Tillage increases aeration and temperature promoting residue decomposition and N mineralization (Mitchell and Teel, 1977), thus more N is released more quickly from incorporated residues (Wilson and Hargrove, 1986; Varco et al., 1993; Mohr et al., 1998a, 1998c). In addition, incorporation of alfalfa residues may reduce gaseous N losses and consequently result in a greater supply of mineral N (Janzen and McGinn, 1991; Mohr et al., 1998b). Similarly, in our study, tillage method resulted in greater accumulation of nitrate-N in soil than herbicide alone termination method. Also, termination after cut 1 had the highest and termination in spring had the lowest amount of nitrate-N in the 0-15 and/or 15-30 cm soil layers in autumn 2003 or in spring 2004. This also suggests downward movement of nitrate-N in the soil profile, most likely due to increased duration for N mineralization and greater

moisture in autumn after cut 1 (Bullied and Entz, 1999), and incorporation of alfalfa residue into the soil by tillage resulting in more N mineralization, as suggested by Mohr et al. (1998b).

3.1.2. Seed and straw yield

In the first crop year (2004) after alfalfa stand termination, there was a significant effect of termination method, termination time, N rate, and their respective 2- and 3-way interactions on seed yield of wheat (**Table 6**). Averaged across N rate and termination time treatments, herbicide method produced substantially lower seed yield than tillage and herbicide + tillage methods, with no significant difference between the latter two methods. Averaged across N rate and termination method, there were significant differences in seed yield for termination times with cut 1 > spring > cut 2.

The significant termination method x termination time interaction occurred because seed yield was maximum when alfalfa stand was terminated in spring for the herbicide method, but seed yield was maximum for tillage and herbicide + tillage methods when the stand was terminated after cut 1 (**Table 6**). The reduction in seed yield from delay in stand termination with tillage and herbicide + tillage was probably due to shorter period for mineralization of nutrients from alfalfa residues incorporated into soil. For the herbicide stand termination method, herbicide application in spring may have reduced weed pressure during early plant growth period under no-till conditions until the in-crop blanket herbicide application to control weeds. Plots terminated after cut 2 by herbicide and herbicide + tillage were not sprayed in spring of 2004, because there was no alfalfa or weed growth observed in these plots, but alfalfa re-growth in these plots was observed on June 16, 2004.

Termination method x N rate interaction resulted from the greater effect of N rate for the herbicide compared to the other termination methods, though a significant increase in seed yield occurred up to 80 kg N ha^{-1} in all the three stand termination methods (**Table 6**). Application of 120 kg N ha^{-1} increased seed yield by 1619, 1278, and 1145 kg ha^{-1} with herbicide, tillage, and herbicide + tillage stand termination methods, respectively. Seed yield was always significantly lower with herbicide compared to other termination methods, but the differences became relatively smaller with the increase in N rate. For example, tillage and herbicide + tillage produced 1101 and 1300 kg ha^{-1} more seed yield than herbicide method at 0 kg N ha^{-1}, respectively; and the corresponding differences declined to 760 and 826 kg ha^{-1} at 120 kg N ha^{-1}.

Termination time x N rate interaction occurred because seed yield was significantly greater after cut 1 at the 0 and 40 kg N ha^{-1} rates, but significantly higher after spring termination at the 80 and 120 kg N ha^{-1} rates compared to other termination times. In general, increase in seed yield due to N fertilization became progressively greater with delay in stand termination time (**Table 6**). Application of 120 kg N ha^{-1} for example, increased seed yield by 828, 1252, and 1962 kg ha^{-1} with stand termination after cut 1, after cut 2 and in spring, respectively compared to 0 kg N ha^{-1}. Significant increase in seed yield occurred up to 40 kg N ha^{-1} for termination after cut 1 and up to 80 kg N ha^{-1} for termination after cut 2 or in spring. Thus, delay in stand termination negatively influenced seed yield at the 0 and 40 kg N ha^{-1}, but not at the 80 and 120 kg N ha^{-1} rates, suggesting that appropriate N fertilization can be used to compensate for the delay in stand termination of alfalfa.

Termination method x termination time x N rate interaction effect on seed yield showed that the increase in seed yield with the N rate was relatively greater with herbicide compared to tillage or herbicide + tillage termination methods (**Table 6**). The increase in seed yield with the N rate became greater with delay in termination for the tillage or herbicide + tillage methods, but the influence of N rate with herbicide method was minimum with termination after cut 2 and maximum with the spring termination. The differences in seed yield increase with N fertilization under herbicide and other termination methods were much greater for termination after cut 1 than the later termination times. For example, application of 120 kg N ha^{-1} to after cut 1 termination treatments increased seed yield by 1656, 353, and 476 kg ha^{-1} with herbicide, tillage and herbicide + tillage methods, respectively; and the corresponding values for the spring termination were 2028, 1972, and 1887 kg ha^{-1} compared to 0 kg N ha^{-1}. Also, the differences in seed yield produced with different termination methods were relatively greater at lower than higher N rates and with earlier than later termination time.

For straw yield, there was a significant effect of termination method, termination time, N rate, and interaction of termination method x termination time (**Table 6**). In general, straw yield showed similar trend for the effects of stand termination method, termination time and N rate as seed yield, though the interactions of N rate with stand termination method and termination time were not significant for straw yield.

Overall, in the first crop year (2004) after alfalfa stand termination, delay in stand termination with tillage and herbicide + tillage decreased seed and straw yield of wheat in the 0 and 40 kg N ha^{-1}

treatments, while spring stand termination using herbicide had the highest seed and straw yield in the herbicide treatment at all N rates. Herbicide method produced less seed and straw yield than tillage and herbicide + tillage, and the differences between herbicide and other methods declined with the increase in N rate. A significant increase in seed and straw yield occurred up to 80 kg N ha^{-1} in most of the treatments. There was no additional benefit in seed and straw yield when herbicide was used in combination with tillage for stand termination. Stand termination by herbicide or delay in stand termination with tillage resulted in increased seed and straw yield response of wheat to N fertilization, indicating reduced N supply from soil and alfalfa residues. Our present results are in agreement with the findings of Malhi et al. (2007) in northeastern Saskatchewan, who also reported lower seed yield of wheat, canola, barley and pea with termination by herbicide alone compared to tillage or herbicide + tillage termination methods. Seed yield of all crops tended to decline with delay in termination time from after cut 1 or 2 to termination in spring. The reduction in seed yield due to herbicide method and delay in termination was associated with lower levels of nitrate-N in soil in spring in herbicide alone or spring termination compared to other treatments. Similarly, in earlier studies in Saskatchewan seed yield of wheat was lower when a green manure crop or alfalfa was terminated using herbicides rather than tillage (Biederbeck and Slinkard, 1988; Bullied et al., 1999).

3.1.3. Seed quality

In 2004, there was a significant effect of termination method, termination time, N rate and interaction of termination method x termination time on protein concentration in seed of wheat (**Table 6**). The highest protein concentration in seed was with the herbicide termination method, particularly with termination after cut 2, which most likely reflected the lower seed yield in these treatments. Conversely, other research has shown reduced protein concentration in seed of wheat, canola, barley and pea with herbicide alone compared to tillage or herbicide + tillage termination methods (Mohr et al., 1999; Malhi et al., 2007). In a study in Manitoba, Mohr et al. (1999) observed higher protein concentration of wheat seed for the early compared to delayed termination. Earlier research has observed increase in protein concentration of wheat seed with N fertilization (Fowler and Brydon, 1991). However, in our study protein concentration in wheat seed was increased only slightly with increasing N rate (147 to 151 g kg^{-1}). This may be due to a dilution effect from substantial increase in seed yield with N fertilization.

There was a significant effect of termination method, termination time, N rate, and their respective two-way interactions on TSW of wheat in 2004 (**Appendix 1**). The TSW of wheat seed was higher with tillage (32.2 g) or herbicide + tillage (32.3 g) compared to herbicide alone (29.6 g) termination method, in spite of higher seed yield of wheat in these treatments. The TSW increased with increasing N rate from zero-N up to 120 kg N ha^{-1} in 2004 (range of 29.9 g to 33.1 g). The TSW was higher with termination after cut 1 (31.7 g) or cut 2 (31.6 g) compared to termination in the following spring (30.8 g). The effects of other treatments and interactions were not significant.

3.1.4. Nitrogen uptake in seed and straw

Like seed yield of wheat, there was a significant effect of termination method, termination time, N rate, and their respective two- and three-way interactions on N uptake in seed of wheat in 2004 (**Table 6**). Although the magnitude of the increases in N uptake were somewhat less than the respective increase in seed yield due to yield dilution, the response pattern of N uptake in seed of wheat was identical to the seed yield response.

For N uptake in straw, there was a significant effect of termination method, termination time, N rate, and interaction of termination method x termination time (**Table 6**). The interactions of N rate with stand termination method and termination time were not significant for the N uptake in straw. The trends for response of N uptake in straw stand termination method, termination time and N rate were generally similar to straw yield.

3.1.5. Recovery of applied N in seed and straw

The percent recovery of applied N in seed was significantly affected by termination method, termination time, N rate and termination method x termination time interaction (**Table 6**). Overall, percent recovery of applied N in seed was lower ($p<0.10$) for herbicide + tillage method than other termination methods, and increased with delay in termination. N uptake in wheat seed increased significantly with each delay in termination (i.e., cut 1 < cut 2 < spring) on the tillage method. The same pattern occurred on the herbicide + tillage method although the final increase was not significant. It is known that if the N contribution from soil increases, then the contribution of fertilizer N to N uptake decreases. Therefore, on the tillage and herbicide + tillage treatments, the lower seed N recovery after cut 1 compared to cut 2 or spring was most likely due to higher

mineralization rates due to tillage and the longer period for mineralization to occur. This greater N release resulted in a proportionate reduction in fertilizer N recovery by the crop. However, on the herbicide method, there was no significant change in fertilizer N recovery with delay in termination. Numerically, fertilizer N recovery was lowest with termination after cut 2. We have no explanation for this result. The N recovery in seed increased from 29.9-49.6% when N rate was increased from 40 to 120 kg N ha^{-1}. This was not expected as percent recovery of applied N generally decreases with increasing N rate. This strong linear response of seed N recovery to applied N at higher rates suggests that the soil was very deficient in available N and soil moisture was not a limiting factor. The effects of termination method and termination time on the percent recovery of applied N in straw were in general similar to seed (**Table 6**).

3.1.6. Nitrous oxide gas emissions

Mean cumulative N_2O loss during 2004 ranged from 220 to 420 g N ha^{-1} (**Table 14**) The range of cumulative N_2O emission values are consistent with those reported for other unfertilized systems under similar environmental conditions (Lemke et al., 1999; Corre et al., 1996). Previous work in the parkland region has shown that N_2O loss during the snow melt period can represent a substantial portion of total annual losses. In 2004, there were negligible emissions during this time period (data not shown) likely due to dry conditions during the previous fall and limited snow cover. Precipitation during August and September of 2003 was only 56% of long-term average. Cumulative N_2O loss was not influenced by timing of the termination, and there were no significant interactions between termination method and timing. Emissions from stands terminated by tillage were significantly higher than those terminated by herbicides in 2004. This was most likely related to lower soil nitrate levels in the untilled (herbicide method) plots.

3.2. Year 2, 3 and 4 Effects of Alfalfa Termination on Soil Mineral N, Crop Yield, Seed Quality, N Uptake, Recovery of Applied N and Nitrous Oxide Emissions

3.2.1. Soil mineral N

In spring 2005 sampling, there was no effect of alfalfa termination method and time on the concentration of nitrate-N and ammonium-N in soil (**Table 7**). This indicated that the effect of termination was diminished after the first cropping season. In spring 2006 sampling, there was a

significant effect of termination method on the concentration of nitrate-N in the 0-15 cm soil depth (**Table 8**). For concentration of ammonium-N in soil, there was essentially no effect of alfalfa termination method, time and their interaction. In spring 2007 sampling, alfalfa termination time and N rate had no effect on the concentration of ammonium-N in soil (**Table 9**). The concentration of nitrate-N in 0-15 cm soil depth tended to increase with N rate, with highest at 120 kg N ha^{-1} rate. In autumn 2007 sampling, there was no significant effect of termination time, termination method, N rate or their interactions on soil ammonium-N and nitrate-N (**Table 10**). It is possible that drought and/or dry moisture conditions in the 2001, 2002, and also 2003 growing seasons may have limited N_2 fixation by alfalfa, and subsequently resulting in short-term residual effects on plant-available N in soil, as evidenced for soil nitrate-N in our study.

3.2.2. Seed and straw yield

In the second crop year (2005) after alfalfa termination, there was no significant effect of termination method, termination time or their interaction on seed and straw yield of canola (**Table 11**). Mean effect of N rate was significant and substantial for both seed and straw yield. Seed yield increased up to 120 kg N ha^{-1}, and straw yield increased up to 80 kg N ha^{-1} rate. The responsiveness of canola seed yield to N application in Saskatchewan soils has been well established in field experiments (Nuttall et al., 1987; Malhi and Gill, 2004). Interaction effect of termination method x N rate was not significant for any of the canola parameters measured, but the interaction effect of termination time x N rate was significant at $P<0.05$ for straw yield. Straw yield at the 0 and 120 kg N ha^{-1} rates became progressively greater with delay in stand termination time, but straw yield decreased with delay in termination time on the 40 kg N ha^{-1} rate and remained similar across the termination times for the 80 kg N ha^{-1} rate. Termination method x time x N rate interaction effect was not significant for seed yield, but it was significant at $P<0.05$ for straw yield (**Table 3**). Straw yield without N fertilizer was usually greater with herbicide alone than other termination methods. Straw yield with N rate became greater with the delay in stand termination, and maximum straw yield was produced for termination in spring with tillage + herbicide.

In the third year after alfalfa termination (2006), time of termination had no effect on seed and straw yield of wheat (**Table 12**). Termination method had significant effect on both seed and straw yield, and seed and straw yields were lower in herbicide alone (no-till) than tillage and herbicide +

tillage treatments. Nitrogen fertilization had a significant effect on seed and straw yield. Seed and straw yield increased considerably with increasing N rate, with maximum yield usually at 120 kg N ha^{-1}. Termination method x N rate interaction was significant for seed and straw yield. These significant interactions can be explained by differences in the magnitude of response to N application. Significant increases in seed yield occurred up to the 120 kg N ha^{-1} rate for the tillage and herbicide + tillage termination methods, but only to the 80 kg rate for the herbicide termination method. For straw yield, the herbicide treatment had a much larger yield response to the first increment of N applied (40 kg ha^{-1}) compared to the other two termination methods. Interaction effect of termination time x N rate, and termination method x termination time x N rate was not significant for these parameters.

In the fourth year after alfalfa termination (2007), time and method of termination had no effect on seed and straw yield of canola (**Table 13**). Seed and straw yield were similar in herbicide alone (no-till), tillage and herbicide + tillage treatments. Nitrogen fertilization had a significant effect on seed and straw yield. Seed and straw yield increased considerably with increasing N rate, with maximum seed yields usually at 120 kg N ha^{-1} rate and seed yields at 80 kg N ha^{-1} rate. Termination method x N rate interaction was not significant for seed and straw yield. This resulted in similar seed and straw yield in herbicide alone, tillage and herbicide + tillage termination treatments, regardless of the rate of N fertilization. Interaction effect of termination time x N rate, and termination method x termination time x N rate was not significant for these parameters.

3.2.3. Seed quality

In 2005, termination method and termination time had no effect on protein concentration in canola seed, but protein concentration increased significantly when N rate was increased from 0 to 120 kg N ha^{-1} (185 to 240 g protein kg^{-1}) (**Table 11**). Similarly, Malhi and Gill (2004) showed linear increase in protein concentration in canola seed with N fertilization rate in northeastern Saskatchewan. Oil concentration in canola seed in 2005 tended to be higher (not significant) when alfalfa stand was terminated by tillage or herbicide + tillage compared to herbicide method (**Table 11**). Oil concentration in canola seed increased with delay in stand termination (441 g oil kg^{-1} for termination after cut 1 to 456 g oil kg^{-1} for termination in spring). Unlike protein concentration, the oil concentration in seed decreased significantly with increasing N rate. Similar to our results, in

another field study in northeastern Saskatchewan, oil content in canola seed was linearly reduced by N fertilization rate (i.e., 45.7, 44.6, 43.3 and 42.4 % oil at 0, 40, 80 and 120 kg N ha^{-1}, respectively) (Malhi and Gill, 2004). There was no significant effect of termination time, termination method and N rate on TSW of canola seed (**Appendix 1**).

In 2006, termination method and termination time had little effect on protein concentration in wheat seed, but protein concentration increased significantly when N rate was increased from 0 to 120 kg N ha^{-1} (138 to 177 g protein kg^{-1}) (**Table 12**). There was a significant effect of N rate on TSW of wheat seed (**Table 3**), and it increased with increasing N rate from zero-N up to 80 kg N ha^{-1} (range of 30.8 g to 33.3 g) (**Appendix 1**). The effects of other treatments and interactions were not significant.

In 2007, termination method and termination time had no effect on protein concentration in canola seed, but protein concentration increased significantly when N rate was increased from 0 to 120 kg N ha^{-1} (179 to 219 g protein kg^{-1}) (**Table 13**). Like protein concentration, oil concentration in canola seed was not affected by termination method or termination time (**Table 13**). Unlike protein concentration, the oil concentration in seed decreased significantly with increasing N rate. There was little and inconsistent effect (but significant) of termination method and N rate on TSW of canola seed (**Appendix 1**).

Earlier studies (Sheppard and Bates, 1980; Nuttall et al., 1987) have shown increase of protein concentration and decrease of oil concentration in canola seed with application of increasing rate of N. Bhatty (1964) observed a negative correlation between protein concentration and oil concentration of rapeseed. The reduction in oil concentration with increasing N rate can be attributed to extension of pod development phase due to N fertilization and subsequent increase in the number of not fully mature seeds with lower oil content (Scott et al., 1973). Delayed plant maturity with N application was considered a most probable reason for the reduction in oil concentration in canola seed, as suggested by Jackson (2000). Ridley (1973) suggested that maximum protein plus oil concentration in rapeseed is approximately fixed, so if one of them increases the other decreases. In addition, higher seed production with more N may have resulted in some dilution of oil concentration.

3.2.4. Nitrogen uptake in seed and straw

In 2005, there was a significant effect of termination time on N uptake in canola seed,

termination method on N uptake in straw, but the effect of N rate was significant for N uptake in both seed and straw (**Table 11**). Seed N uptake decreased with delay in termination time. Straw N uptake was higher when stand was terminated by herbicide compared to tillage or herbicide + tillage. The N uptake in both seed and straw increased up to 120 kg N ha^{-1}. In the absence of N fertilization, N uptake in straw became greater with delay in stand termination, with the highest N uptake for spring termination. Maximum N uptake in straw was produced at 80 kg N ha^{-1} for termination after cut 1 and cut 2, but it occurred at 120 kg N ha^{-1} when the stand was terminated in spring. Actual N uptake in straw without N fertilization became progressively greater, but the increase in N uptake in straw from N fertilization diminished with delay in termination. Application of 120 kg N ha^{-1} for example, increased N uptake in straw by 18, 17 and 14 kg N ha^{-1} with stand termination after cut 1, after cut 2 and in spring, respectively. For all termination times, maximum N uptake in straw occurred at 120 kg N ha^{-1}. Termination method x time x N rate interaction effect was not significant for N uptake in seed, but it was significant at $P<0.08$ for N uptake in straw.

In the third year after alfalfa termination (2006), time of termination had little effect on N uptake in seed, and no effect on straw N uptake of wheat (**Table 12**). Termination method had significant effect on both seed and straw N uptake. Seed and straw N uptake were lower in herbicide alone (no-till) than tillage and herbicide + tillage treatments. Nitrogen fertilization had a significant effect on seed and straw N uptake. Seed and straw N uptake increased considerably with increasing N rate, reaching a maximum at 120 kg N ha^{-1}. Interaction effects of termination method x N rate, termination time x N rate, and termination method x termination time x N rate were not significant for these parameters. In 2007, termination method had significant (but small) effect on N uptake in seed and straw. Termination time had no effect on N uptake in seed and straw of canola, but N uptake of both seed and straw increased considerably and significantly when the N rate was increased from 0 to 120 kg N ha^{-1} (**Table 13**).

The short-term residual effects on crop yield and N uptake in our study could be due to the fact that drought and/or dry moisture conditions in the 2001, 2002, and also 2003 growing seasons may have limited N_2 fixation by alfalfa, and subsequently less plant-available N in soil for crop uptake. The differences in the impact of termination methods on crop yield and N uptake between 2005 and 2006 could be due to slightly higher (but significant) nitrate-N in soil with tillage than no-till (herbicide) treatment in 2006 compared to 2005. It is also possible that these differences could be

because of the type of crop species with different rooting system (i.e., long taproot for canola and relatively short fibrous roots for wheat, with different abilities to extract nutrients from surface and subsoil layers).

3.2.5. Recovery of applied N in seed and straw

In 2005, the percent recovery of applied N in seed was lower with herbicide method than the two other termination methods (**Table 11**). The N recovery in seed and straw tended to decrease when termination was delayed, and tended to increase with increasing N rate. In 2006, in general there was no significant effect of termination time, method, or rate of applied N on the percent recovery applied N in seed and straw (**Table 12**). In 2007, termination method and termination time had no effect on the percent recovery of applied N in seed, but termination method had significant effect on the percent recovery of applied N in straw (**Table 13**), with percent recovery being significantly higher on herbicide + tillage than on tillage. The percent recovery of applied N in seed and straw increased slightly but significantly when N rate was increased from 0 to 120 kg N ha^{-1}.

3.2.6. Nitrous oxide gas emissions

Mean cumulative loss of N_2O ranged from 330 to 730 g N ha^{-1} at the zero-N rate in 2005, from 150 to 330 g N ha^{-1} at the zero-N rate in 2006, and from 220 to 425 g N ha^{-1} at the zero-N rate and from 371 to 849 g N ha^{-1} at the 80 kg N ha^{-1} rate in 2007 (**Table 14**). The higher values in 2007 were to be expected as a treatment receiving fertilizer N was included in this year. The range of cumulative N_2O emission values is rather low, but consistent with the values reported for other medium textured Gray Luvisolic soils under similar climactic conditions (Lemke et al., 1999).

Previous work in the parkland region has shown that N_2O loss during the snow melt period can represent a substantial portion of total annual losses. The N_2O emissions during the snow melt period of 2005, 2006 and 2007 were substantially higher than 2004, representing between 16 and 55% of the cumulative seasonal totals reported (data not shown). In 2006, N_2O flux on the first sampling date (April 20) was very high, suggesting that emissions activity may have begun before the first sampling and thus the cumulative N_2O loss may have been somewhat underestimated.

In 2005, N_2O loss was highest from the herbicide treatments and lowest from the tilled treatments, with the herbicide + tillage treatment being intermediate, the reverse of N_2O emissions in

2004. We would expect that N mineralized from residues that were incorporated into the soil (tillage treatments) would be released more quickly than from residues that were not incorporated (herbicide treatments). In the spring of 2005 soil nitrate-N values were significantly higher on herbicide compared to the tilled treatment. We infer that soil nitrate-N availability likely explains why N_2O loss was higher from tilled treatments in 2004, but higher on the herbicide treatment in 2005. In 2006, N_2O loss from the herbicide treatments was again higher than on the tilled treatments, but the difference was smaller and only significant at $p < 0.1$. As expected, there was no influence of termination method by the 2007 field season. Terminating the alfalfa stand with herbicides reduced N_2O emissions in the first year, but that loss was only delayed until the second year and the cumulative loss over the three years was very similar across the termination methods. By the fourth year of the study no residual effects of termination method on N_2O loss was apparent. Timing of stand termination had no significant influence on cumulative N_2O loss in any of the four years, and there was no significant interaction between termination method and timing (**Table 15**).

As expected the application of fertilizer N had a highly significant influence on N_2O loss in 2007. Fertilizer-induced emissions were calculated to be about 0.4 % of applied N which is somewhat lower than might be expected for the parkland region (Rochette et al., 2008), but, as previously mentioned, these values are consistent with other work conducted on medium textured Grey Luvisolic soils.

3.3. Soil Properties after Four Growing Seasons

3.3.1. Soil bulk density

Soil bulk density was significant affected by N application only in the 5-10 cm depth, and by termination time and termination method in the 5-10 cm, and 10-15 cm (at $P \leq 0.10$) depths (**Appendix 2**). Soil bulk density was higher at zero-N rate than 80 kg N ha^{-1} rate, with herbicide no-till method than tillage method, and tended to be higher with termination in spring or after cut 2 than termination after cut 1. Interaction effects were significant (at $P \leq 0.10$) in the 5-10 and 10-15 cm depths for termination time x N rate. This was because of much larger decrease in soil bulk density due to N application when termination was done in spring or after cut 2 and no effect of N fertilizer on soil bulk density when alfalfa stand was terminated after cut 1 in the 5-10 cm depth, but no real

trend in the 10-15 cm soil depth. Termination method x termination time x N rate interaction effect was significant in the 0-5, 10-15 and 15-20 cm soil depths, but significant only at $P \leq 0.10$ in 2 of 3 cases.

Overall, our findings indicate that soil bulk density was decreased with N application, and increased with elimination of tillage, but mainly in the 5-10 cm depth. Previous research has also shown higher soil bulk density and compaction (as determined by penetration resistance) under no-till compared to conventional tillage (Mahi and O'Sullivan, 1990; Singh and Malhi, 2006). The findings of other research (Piece et a., 1993) also suggest that the increase in soil bulk density due to elimination of tillage in our study was small and this bulk density should not be considered to have a negative impact on root growth and/or crop yield.

3.3.2. Soil Organic C and N

There was a significant effect of termination method on TOC and TON in the 0-5 and 5-10 cm soil layers (**Table 16**). The amounts of TOC and TON were higher under herbicide (no-till) than under tillage in the 0-5 cm soil layer, but the opposite occurred in the 5-10 cm soil layer. The effect of termination time and N rate on TOC and TON was significant only in the 0-5 cm soil layer. Spring termination had the lowest amount of TOC and TON in the 0-5 cm soil layer. The amount of TOC and TON in the 0-5 cm soil layer was higher with N application. Interaction effects of termination method, termination time and N rate were not significant for TOC and TON in almost all cases.

For the light fractions, termination method had a significant effect on LFOM, LFOC and LFON in all soil layers (**Table 17**). Like TOC and TON, the amounts of LFOM, LFOC and LFON were higher under herbicide (no-till) than under tillage in the 0-5 cm soil layer, but the opposite was true in the 5-10 and 10-15 cm soil layer. This resulted in a non-significant effect of termination method on the total amount of LFOM, LFOC and LFON in the 0-15 soil depth. The amounts of LFOM, LFOC and LFON tended to be least with spring termination, but the effect was significant only in the 0-15 cm depth for LFOC and LFON. In the 0-5 and 0-15 cm soil layers, the amount of LFOM, LFOC and LFON tended to be higher with 80 kg N ha^{-1} than the zero-N treatment, but the effect was not significant. Interaction effect of termination method x N rate on LFOC and LFON in soil was significant only for the 0-15 cm layer, most likely because of higher LFOC and LFON with 80 kg N ha^{-1} compared to zero-N treatment under tillage treatments, but no effect of N application under

herbicide (no-till) treatment. Termination time x N rate interaction effect on LFOC and LFON was significant in the 0-5 and 0-15 cm soil layers. This was probably due to the fact that applied N increased LFOC and LFON only in treatment with termination after cut 1, but little or no effect of N fertilizer in other treatments. Interaction effects of termination method x termination time, and termination method x termination time x N rate were not significant in any case.

The amounts of TOC, TON, LFOC and LFON were usually higher or tended to be higher under herbicide (no-till) treatment than under tillage treatment in the 0-5 cm soil layer. Similarly, in another short-term tillage study in the same area, no-till had higher TOC and TON in the top layer compared to conventional tillage, especially in a soil inherently low in organic matter (Malhi and Kutcher, 2007). Similar to our results, LFOC and LFON were found to be more sensitive to tillage treatments than TOC and TON in short-term studies (Malhi et al., 2006; Malhi and Kutcher, 2007). Other earlier research has also shown LFOC more sensitive to conservation tillage practices than TOC (Bolinder et al., 1999; Oyedel et al., 1999).

Mixing of soil organic matter and alfalfa residue by tillage most likely resulted in reduced organic C and N in the 0-5cm layer and slightly higher organic C and N in the 5-10 or 10-15 cm soil layers compared to the herbicide method. This also resulted in the lack of differences for TOC, TON, LFOM, LFOC and LFON over the 0-15 cm soil depth. The differences between herbicide and tillage treatments tended to be proportionally higher for light fraction organic C and N than for total organic C and N.

4. Conclusions

Overall, the results indicate that in the first crop year after alfalfa stand termination, N fertilization can be used to compensate for a decline in yield due to the delay in alfalfa stand termination until the spring of the cropping season. The effect of termination performed in summer 2003 or in spring 2004 diminished substantially in the second cropping season, and nearly disappeared by the third cropping season. There was delayed release of mineral N in untilled soils, so herbicide (no-till) termination may reduce the potential for nitrate N loss to the environment if there is potential for large releases of nitrate. The effect of reduced N availability in the immediate year following termination by herbicide can be addressed by nitrogen fertilizer application.

Nitrous oxide emissions following termination of a seven year old alfalfa stand were low. The

timing of the stand termination had no influence on cumulative N_2O loss. The method of stand termination did have an influence on N_2O loss. The herbicide termination method had the lowest N_2O loss in the first year following termination, while tillage method had the highest loss. In the second year following termination the situation was reversed, offsetting the differences in the first year. Thus, when considered on a cumulative basis over a three or four year period, N_2O loss was not affected by method or timing of stand termination. Fertilizer application significantly increased N_2O emissions, with a fertilizer-induced emission coefficient of about 0.4% of applied N, based on one year of data (2007).

The amounts of TOC, TON, LFOC and LFON after four years were usually higher or tended to be higher in the 0-5 cm layer under herbicide (no-till) treatment than under tillage treatment, but the opposite was true in the 5-10 or 10-15 soil cm layers. This resulted in non-significant effect of tillage on these parameters based on a 0-15 cm depth. The amount of TOC and TON increased, and LFOM, LFOC and LFON tended to increase in the 0-5 cm soil layer with N application. Alfalfa termination in spring had or tended to have lowest amount of LFOM, LFOC and LFON. Overall, herbicide (no-till) and N fertilization had or tended to have positive effect on organic C and N, especially light fraction organic C and N. Soil bulk density increased with elimination of tillage but only in the 5-10 cm depth, and it is not considered to have a negative impact on root growth and crop yield.

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Table 1. Monthly precipitation and mean monthly temperatures in 2003, 2004, 2005, 2006 and 2007, and their long-term (1950-2007) means at Melfort, Saskatchewan

	Precipitation (mm)						Temperature (°C)a					
Month	2003	2004	2005	2006	2007	Long Term[a]	2003	2004	2005	2006	2007	Long Term
May	5.1	33.5	44.0	56.0	83.0	45.6	12.1	6.4	8.3	11.3	10.7	10.8
June	11.1	116.7	175.5	70.0	100.0	65.8	15.9	12.5	13.9	16.6	14.4	15.7
July	11.0	53.2	62.7	44.0	61.0	75.5	18.1	16.7	16.9	18.4	20.1	17.4
August	28.6	91.8	47.4	38.0	65.0	56.8	19.9	13.6	14.9	17.1	14.8	16.4
Total/Mean	55.8	295.3	329.5	208.0	309.0	243.7	16.5	12.3	13.5	15.9	15.0	15.1

[a]Long-term precipitation and all temperature values are from the nearest Environment Canada Meteorological Station, Melfort, Saskatchewan.

Table 2. Tillage and herbicide application dates for the three methods (herbicide, tillage, and herbicide + tillage) and three times (after 1st cut and 2nd cut in 2003 and in spring of 2004) of alfalfa stand termination

Stand termination		Herbicide and tillage operation	
Method	Time	Date	Operation
Herbicide	1st cut	23 July 2003	Roundup + 2,4-D amine spray
		26 May 2004	Roundup + 2,4-D amine spray
	2nd cut	3 Sept. 2003	Roundup + 2,4-D amine spray
			Not sprayed in spring 2004, as there was no weed or alfalfa regrowth
	Spring	14 May 2004	Roundup + 2,4-D amine spray
Tillage	1st cut	23 July 2003	Spike cultivation
		24 July 2003	Shovel cultivation
		10 Sept. 2003	Shovel cultivation
		19 May 2004	Shovel cultivation
	2nd cut	3 Sept. 2003	Spike + shovel cultivation
		19 May 2004	Shovel cultivation
	Spring	13 May 2004	Spike + shovel cultivation
Herbicide + Tillage	1st cut	23 July 2003	Roundup + 2,4-D amine spray
		1 Aug. 2003	Spike + shovel cultivation
		10 Sept. 2003	Shovel cultivation
		19 May 2004	Shovel cultivation
		26 May 2004	Roundup + 2,4-D amine spray
	2nd cut	3 Sept. 2003	Roundup + 2,4-D amine spray
		10 Sept. 2003	Spike + shovel cultivation
		19 May 2004	Shovel cultivation
	Spring	14 May 2004	Roundup + 2,4-D amine spray
		19 May 2004	Spike + shovel cultivation

Note: sprayed Lontrel + 2,4-D (in crop) at recommended rates and achieved excellent alfalfa control.

Table 3. The standard error of means (SEM) and significance level of the termination method (M), termination time (T), N rate (N), M x T, M x N, T x N and M x T x N interactions based on the ANOVA for wheat and canola parameters at different M, T and N rates in 2004, 2005, 2006 and 2007 at Star City in northeastern Saskatchewan

Year	Parameter	SEM and significance level[z]						
		M	T	N	M x T	M x N	T x N	M x T x N
2004	Seed yield (kg ha^{-1})	45.3***	45.3***	52.2***	78.3***	90.4*	90.4***	156.7•
	Straw yield (kg ha^{-1})	72.4***	72.4*	83.6***	125.4***	144.8^{ns}	144.8^{ns}	250.9^{ns}
	Protein concentration in seed (g kg^{-1})	0.9***	0.9***	1.1*	1.6***	1.9^{ns}	1.9^{ns}	3.3^{ns}
	Thousand seed weight (g)	0.26***	0.26*	0.30***	0.45**	0.52***	0.52•	0.90^{ns}
	Uptake of N in seed (kg N ha^{-1})	0.95***	0.95***	1.10***	1.64***	1.90***	1.90***	3.29•
	Uptake of N in straw (kg N ha^{-1})	0.69***	0.69•	0.80***	1.20***	1.38^{ns}	1.38^{ns}	2.40^{ns}
	Recovery of applied N in seed (%)	2.52•	2.52***	2.52***	4.36***	4.36^{ns}	4.36^{ns}	7.56^{ns}
	Recovery of applied N in straw (%)	1.23•	1.23*	1.23^{ns}	2.12^{ns}	2.12^{ns}	2.12^{ns}	3.68^{ns}
2005	Seed yield (kg ha^{-1})	23.5^{ns}	23.5^{ns}	27.1***	40.7^{ns}	47.0^{ns}	47.0^{ns}	81.4^{ns}
	Straw yield (kg ha^{-1})	56.5^{ns}	56.5^{ns}	65.2*	98.0^{ns}	113.0^{ns}	113.0•	195.8•
	Protein concentration in seed (g kg^{-1})	1.4^{ns}	1.4*	1.6***	2.4^{ns}	2.7^{ns}	2.7^{ns}	4.7^{ns}
	Oil concentration in seed (g kg^{-1})	3.8**	3.8•	4.4***	6.6^{ns}	7.6^{ns}	7.6^{ns}	13.1^{ns}
	Thousand seed weight (g)	0.02^{ns}	0.02^{ns}	0.02^{ns}	0.03^{ns}	0.04^{ns}	0.04^{ns}	0.06^{ns}
	Uptake of N in seed (kg N ha^{-1})	1.08^{ns}	1.08*	1.25***	1.88^{ns}	2.17^{ns}	2.17^{ns}	3.75^{ns}
	Uptake of N in straw (kg N ha^{-1})	0.59*	0.59^{ns}	0.68***	1.03^{ns}	1.19^{ns}	1.19^{ns}	2.06^{ns}
	Recovery of applied N in seed (%)	2.33*	2.33^{ns}	2.33^{ns}	4.04^{ns}	4.04^{ns}	4.04^{ns}	6.99^{ns}
	Recovery of applied N in straw (%)	1.11^{ns}	1.11**	1.11*	1.92^{ns}	1.92^{ns}	1.92^{ns}	3.33^{ns}
2006	Seed yield (kg ha^{-1})	22.6***	22.6^{ns}	26.0***	39.0^{ns}	45.1*	4.51^{ns}	78.1^{ns}
	Straw yield (kg ha^{-1})	42.7***	42.7^{ns}	49.4***	74.0^{ns}	85.5*	85.5^{ns}	148.0^{ns}
	Protein concentration in seed (g kg^{-1})	1.0^{ns}	1.0•	1.1***	1.65^{ns}	1.90^{ns}	1.90^{ns}	3.3^{ns}
	Thousand seed weight (g)	0.14^{ns}	0.14^{ns}	0.16***	0.24^{ns}	0.28^{ns}	0.28^{ns}	0.48^{ns}
	Uptake of N in seed (kg N ha^{-1})	0.64***	0.64•	0.74***	1.11^{ns}	1.28^{ns}	1.28^{ns}	2.22^{ns}
	Uptake of N in straw (kg N ha^{-1})	0.32***	0.32^{ns}	0.38***	0.56^{ns}	0.65^{ns}	0.65^{ns}	1.13^{ns}
	Recovery of applied N in seed (%)	1.59^{ns}	1.59^{ns}	1.59***	2.76^{ns}	2.76^{ns}	2.76^{ns}	4.78^{ns}
	Recovery of applied N in straw (%)	0.63^{ns}	0.63^{ns}	0.63^{ns}	1.09*	1.09^{ns}	1.09^{ns}	1.89^{ns}
2007	Seed yield (kg ha^{-1})	16.1^{ns}	16.1^{ns}	18.6***	27.9^{ns}	32.2^{ns}	32.2^{ns}	55.8^{ns}
	Straw yield (kg ha^{-1})	17.0^{ns}	17.0^{ns}	54.3***	81.4•	94.0^{ns}	94.0^{ns}	162.8^{ns}
	Protein concentration in seed (g kg^{-1})	0.83^{ns}	0.83^{ns}	0.96***	1.44•	1.66^{ns}	1.66^{ns}	2.87^{ns}
	Oil concentration in seed (g kg^{-1})	0.7^{ns}	0.7^{ns}	0.8***	1.2•	1.4^{ns}	1.4^{ns}	2.4^{ns}
	Thousand seed weight (g)	0.02**	0.02^{ns}	0.02***	0.03**	0.03^{ns}	0.03^{ns}	0.06^{ns}
	Uptake of N in seed (kg N ha^{-1})	0.56•	0.56^{ns}	0.65***	0.97^{ns}	1.11^{ns}	1.11^{ns}	1.94^{ns}
	Uptake of N in straw (kg N ha^{-1})	0.37*	0.37^{ns}	0.43***	0.64•	0.74^{ns}	0.74^{ns}	1.28^{ns}
	Recovery of applied N in seed (%)	1.42^{ns}	1.42^{ns}	1.42•	2.46•	2.46^{ns}	2.46^{ns}	4.25^{ns}
	Recovery of applied N in straw (%)	0.77**	0.77^{ns}	0.77*	1.33*	1.33^{ns}	1.33^{ns}	2.31^{ns}

[z] ***, **, *, •, and ^{ns} with the SEM indicate the treatment effect being significant at $P < 0.001$, $P < 0.01$, $P < 0.05$, 0.10 and not significant, respectively.

Table 4. Soil ammonium-N (NH_4-N) and nitrate-N (NO_3-N) concentration in the 0-15, 15-30 and 30-60 cm depths for three termination methods and three termination times for the zero-N treatment in autumn 2003 at Star City, Saskatchewan

Stand termination		Concentration of NH_4-N (mg N kg^{-1}) in soil depths (cm)			Concentration of NO_3-N (mg N kg^{-1}) in soil depths (cm)		
Method	Time	0-15	15-30	30-60	0-15	15-30	30-60
Herbicide	Cut 1	4.5	5.6	4.2	3.4	0.7	0.4
Herbicide	Cut 2	4.1	4.7	5.4	4.5	0.4	0.4
Tillage	Cut 1	5.1	5.8	4.3	21.3	1.0	0.5
Tillage	Cut 2	5.7	7.1	6.4	12.6	0.4	0.4
Herbicide + Tillage	Cut 1	5.6	7.0	6.0	20.0	2.2	0.6
Herbicide + Tillage	Cut 2	7.2	7.1	6.3	12.6	0.5	0.4
	Spring	5.2	6.9	6.1	1.1	0.2	0.4
$LSD_{0.05}$		1.9	ns	ns	4.6	1.2	ns
SEM		0.65•	0.71^{ns}	0.76^{ns}	1.56***	0.42*	0.06^{ns}

•, *, *** and ns refer to the treatment effect being significant at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.001$ and not significant, respectively.

Table 5. Soil ammonium-N (NH_4-N) and nitrate-N (NO_3-N) concentration in the 0-15, 15-30 and 30-60 cm depths for three termination methods and three termination times for the zero-N treatment in spring 2004 at Star City, Saskatchewan

Stand termination		Concentration of NH_4-N (mg N kg^{-1}) in soil depths (cm)			Concentration of NO_3-N (mg N kg^{-1}) in soil depths (cm)		
Method	Time	0-15	15-30	30-60	0-15	15-30	30-60
				Method x Time			
Herbicide	Cut 1	4.4	4.9	3.6	3.1	2.2	0.6
	Cut 2	4.5	6.1	5.0	5.4	2.0	1.0
	Spring	4.8	6.3	4.4	1.9	0.7	0.7
Tillage	Cut 1	5.4	7.0	4.7	14.1	9.3	1.9
	Cut 2	4.6	5.5	4.3	8.3	4.6	1.4
	Spring	4.9	5.5	4.0	1.9	0.5	0.5
Herbicide + Tillage	Cut 1	4.9	5.8	3.7	12.9	10.3	1.7
	Cut 2	4.4	5.4	3.4	11.8	6.1	1.4
	Spring	4.9	5.4	3.8	1.8	1.3	1.0
	$LSD_{0.05}$	ns	1.4	0.9	1.9	1.9	0.7
	SEM	0.31^{ns}	0.46*	0.32*	0.66***	0.65***	0.24•
				Method			
Herbicide		4.6	5.7	4.3	3.5	1.6	0.8
Tillage		4.9	6.0	4.3	8.1	4.8	1.3
Herbicide + Tillage		4.7	5.5	3.6	8.8	5.9	1.4
	$LSD_{0.05}$	ns	ns	0.6*	1.1***	1.1***	0.4*
	SEM	0.18^{ns}	0.27^{ns}	0.19*	0.38***	0.37***	0.14*
				Time			
	Cut 1	4.9	5.9	4.0	10.0	7.3	1.4
	Cut 2	4.5	5.7	4.2	8.5	4.2	1.3
	Spring	4.9	5.7	4.1	1.8	0.8	0.7
	$LSD_{0.05}$	ns	ns	ns	1.1***	1.1***	0.4**
	SEM	0.18^{ns}	0.27^{ns}	0.19^{ns}	0.38***	0.37***	0.14**

• *, **, *** and ns refer to the treatment effect being significant at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

Table 6a. Seed and straw yield, protein concentration in seed, N uptake in seed and straw, recovery of applied N in seed and straw of wheat for three termination methods, three termination times and method x time interaction in 2004 at Star City, Saskatchewan

Stand termination		Seed yield	Straw yield	Protein conc.	N uptake in seed	N uptake in straw	Recovery of applied N in seed	Recovery of applied N in straw
Method	Time	(kg ha^{-1})	(kg ha^{-1})	(g kg^{-1})	(kg N ha^{-1})	(kg N ha^{-1})	(%)	(%)
					Method x Time			
Herbicide	Cut 1	1879	2928	153	49.3	28.6	45.5	11.19
	Cut 2	1562	2688	162	43.2	26.6	33.3	9.79
	Spring	2362	3596	147	59.1	32.7	44.5	14.12
Tillage	Cut 1	3330	4086	144	81.5	34.2	25.9	4.42
	Cut 2	2855	3879	147	70.7	32.1	39.8	10.37
	Spring	2803	3864	145	69.5	30.0	56.4	10.01
Herbicide + Tillage	Cut 1	3275	4250	146	81.5	35.1	18.0	6.29
	Cut 2	2967	3976	146	73.8	33.1	37.2	12.50
	Spring	2774	3775	144	68.1	32.0	47.1	10.31
	$LSD_{0.05}$	220	352	5	4.6	3.4	12.3	ns
	SEM	78.3***	125.4***	1.7***	1.64***	1.20***	4.36***	2.12^{ns}
					Method			
Herbicide		1934	3071	154	50.5	29.3	41.1	11.7
Tillage		2989	3940	146	73.8	32.1	41.1	8.4
Herbicide + Tillage		3005	4000	145	74.5	33.4	34.4	9.7
	$LSD_{0.05}$	127	203	3	2.7	1.9	7.1	3.5
	SEM	45.3***	72.4***	0.9***	0.95***	0.69***	$2.52^{\bullet}$	$1.23^{\bullet}$
					Time			
	Cut 1	2817	3748	148	70.7	32.6	29.9	7.4
	Cut 2	2461	3515	152	62.6	30.6	36.8	10.9
	Spring	2646	3745	145	65.6	31.6	49.6	11.5
	$LSD_{0.05}$	127	203	3	2.7	1.9	7.1	3.5
	SEM	45.3***	72.4*	0.9***	0.95***	$0.69^{\bullet}$	2.52***	1.23*

$^{\bullet}$, * and *** refer to the treatment effect being significant at $P \leq 0.10$, $P \leq 0.05$ and $P \leq 0.001$, respectively.

Table 6b. Seed and straw yield, protein concentration in seed, N uptake in seed and straw, recovery of applied N in seed and straw of wheat for four N rates, termination method x N rate interaction and termination time x N rate interaction in 2004 at Star City, Saskatchewan

Treatment: Termination Method/Time	Treatment: N rate (kg ha^{-1})	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Protein conc. (g kg^{-1})	N uptake in seed (kg N ha^{-1})	N uptake in straw (kg N ha^{-1})	Recovery of applied N in seed (%)	Recovery of applied N in straw (%)
					Method x N Rate			
Herbicide	0	1001	2221	154	26.2	22.3		
	40	1644	2912	152	42.2	27.3	39.9	12.5
	80	2472	3382	153	64.1	30.7	47.3	10.5
	120	2620	3769	158	69.7	36.8	36.2	12.1
Tillage	0	2102	3366	145	51.8	27.1		
	40	2951	3979	144	72.3	30.4	51.3	8.3
	80	3440	4120	145	84.7	33.4	41.2	8.0
	120	3560	4328	147	87.4	37.9	29.9	9.0
Herbicide + Tillage	0	2301	3458	142	55.5	27.5		
	40	2968	4057	143	72.5	31.6	42.5	10.4
	80	3304	3961	148	82.9	33.3	34.3	7.2
	120	3446	4525	149	87.0	41.2	26.3	11.5
$LSD_{0.05}$		254	ns	ns	5.3	ns	ns	ns
SEM		90.4*	144.8^{ns}	1.9^{ns}	1.90***	1.38^{ns}	4.36^{ns}	2.12^{ns}
					Time x N Rate			
Cut 1	0	2238	3316	146	54.6	27.8		
	40	2838	3705	145	69.8	30.0	38.1	5.6
	80	3059	3737	149	77.4	32.8	28.5	6.2
	120	3163	4276	152	81.5	40.5	22.4	10.6
Cut 2	0	1667	2842	152	42.2	24.1		
	40	2350	3464	153	59.8	28.5	44.0	11.1
	80	2910	3775	151	73.9	32.8	39.6	10.9
	120	2919	3977	153	74.3	36.9	26.8	10.7
Spring	0	1500	2886	144	36.7	25.0		
	40	2375	3779	142	57.4	30.8	51.6	14.5
	80	3247	3951	145	80.4	31.8	54.6	8.5
	120	3462	4366	149	87.8	38.7	42.6	11.5
$LSD_{0.05}$		254	ns	ns	5.3	ns	ns	ns
SEM		90.4***	144.8^{ns}	1.9^{ns}	1.90***	1.38^{ns}	4.36^{ns}	2.12^{ns}
					N Rate			
	0	1802	3015	147	44.5	25.6		
	40	2521	3650	147	62.3	29.8	44.6	10.4
	80	3072	3821	149	77.2	32.5	40.9	8.5
	120	3182	4204	151	81.2	38.7	30.8	10.9
	$LSD_{0.05}$	146	235	3	3.1	2.2	7.1	ns
	SEM	52.2***	83.6***	1.1*	1.10***	0.80***	2.52***	1.23^{ns}
	Linear	0.919*	0.948*	0.891*	0.939*	0.975**	0.933*	0.408^{ns}
	Quadratic	0.997**	0.969*	0.982*	0.996**	0.986*	1.00**	1.00**

*, **, *** and ns refer to the treatment effect being significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

Table 6c. Seed and straw yield, protein concentration in seed, N uptake in seed and straw, recovery of applied N in seed and straw of wheat for termination method x termination time x N rate interaction in 2004 at Star City, Saskatchewan

Treatment			Seed yield	Straw yield	Protein conc.	N uptake in seed	N uptake in straw	Recovery of applied N in seed	Recovery of appliedN in straw
Termination		N rate							
Method	Time	(kg N ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(g kg^{-1})	(kg N ha^{-1})	(kg N ha^{-1})	(%)	(%)
						Method x Time x N Rate			
Herbicide	Cut 1	0	889	2031	152	23.2	21.8		
		40	1692	2858	150	43.3	26.5	50.1	11.8
		80	2390	3252	152	62.0	29.9	48.5	10.0
		120	2545	3572	159	68.8	36.0	38.0	11.8
	Cut 2	0	863	2042	161	23.8	20.6		
		40	1322	2436	165	37.1	23.9	33.3	8.2
		80	2030	3146	159	55.1	30.0	39.2	11.8
		120	2035	3130	164	56.8	31.9	27.5	9.4
	Spring	0	1252	2591	149	31.7	24.5		
		40	1920	3442	141	46.2	31.5	36.3	17.6
		80	2995	3748	147	75.1	32.3	54.2	9.7
		120	3280	4605	149	83.4	42.5	43.1	15.1
Tillage	Cut 1	0	2804	3938	144	68.4	31.2		
		40	3409	4132	144	83.1	32.4	36.9	3.0
		80	3617	4120	142	87.7	35.1	24.1	4.8
		120	3543	4175	148	88.8	39.4	13.1	5.8
	Cut 2	0	1924	3217	151	48.8	25.5		
		40	2744	3692	147	68.2	28.9	48.4	8.4
		80	3319	4074	148	82.7	34.3	42.4	11.0
		120	3434	4536	144	83.1	39.7	28.6	11.8
	Spring	0	1579	2942	142	38.1	24.5		
		40	2699	4114	142	65.6	29.9	68.7	13.5
		80	3383	4164	145	83.7	30.8	57.0	7.9
		120	3551	4234	150	90.5	34.9	43.7	8.7
Herbicide + Tillage	Cut 1	0	3020	3980	141	72.1	30.3		
		40	3411	4125	143	83.0	31.1	27.3	2.2
		80	3171	3840	153	82.5	33.3	13.0	3.8
		120	3496	5054	149	88.6	45.7	13.8	12.9
	Cut 2	0	2214	3270	144	54.1	26.2		
		40	2985	4266	146	74.2	32.9	50.2	16.7
		80	3380	4104	146	83.8	34.2	37.1	10.0
		120	3288	4263	149	83.1	39.2	24.2	10.8
	Spring	0	1669	3124	142	40.2	25.9		
		40	2507	3780	142	60.2	30.9	50.0	12.4
		80	3363	3939	144	82.4	32.2	52.7	7.8
		120	3556	4258	148	89.4	38.8	41.0	10.7
		$LSD_{0.05}$	439	ns	ns	9.2	ns	ns	ns
		SEM	156.7•	250.9^{ns}	3.3^{ns}	3.29•	2.40^{ns}	7.56^{ns}	3.68^{ns}

• and ns refer to the treatment effect being significant at $P \leq 0.10$ and not significant, respectively.

Table 7. Soil ammonium-N (NH_4-N) and nitrate-N (NO_3-N) concentration in the 0-15, 15-30 and 30-60 cm depths for three termination methods and three termination times for the zero-N treatment in spring 2005 at Star City, Saskatchewan

Stand termination		Concentration of NH_4-N (mg N kg^{-1}) in soil depths (cm)			Concentration of NO_3-N (mg N kg^{-1}) in soil depths (cm)		
Method	Time	0-15	15-30	30-60	0-15	15-30	30-60
				Method x Time			
Herbicide	Cut 1	6.6	5.9	4.1	9.2	3.1	2.0
	Cut 2	5.8	6.8	5.7	9.4	3.0	2.2
	Spring	5.5	5.9	4.3	10.2	2.2	1.6
Tillage	Cut 1	5.5	6.2	4.9	7.6	2.8	2.0
	Cut 2	5.6	7.7	5.2	8.5	3.5	1.7
	Spring	5.5	6.2	4.9	8.1	2.5	1.6
Herbicide + Tillage	Cut 1	6.0	7.1	5.0	8.7	3.2	1.7
	Cut 2	5.8	8.0	4.8	10.2	2.7	1.6
	Spring	5.4	6.5	5.0	6.8	2.2	1.9
	$LSD_{0.05}$	ns	ns	ns	ns	ns	ns
	SEM	0.51^{ns}	0.73^{ns}	0.49^{ns}	0.94^{ns}	0.34^{ns}	0.23^{ns}
				Method			
Herbicide		6.0	6.2	4.7	9.6	2.8	2.0
Tillage		5.5	6.7	5.0	8.1	2.9	1.8
Herbicide + Tillage		5.7	7.2	4.9	8.6	2.7	1.7
	$LSD_{0.05}$	ns	1.23	ns	ns	ns	ns
	SEM	0.29^{ns}	$0.42^{\bullet}$	0.28^{ns}	0.54^{ns}	0.20^{ns}	0.13^{ns}
				Time			
	Cut 1	6.1	6.4	4.7	8.5	3.1	1.9
	Cut 2	5.7	7.5	5.2	9.3	3.0	1.9
	Spring	5.5	6.2	4.7	8.4	2.3	1.7
	$LSD_{0.05}$	ns	ns	ns	ns	0.6	ns
	SEM	0.29^{ns}	0.42^{ns}	0.28^{ns}	0.54^{ns}	0.20^{*}	0.13^{ns}

$^{\bullet}$, * and ns refer to the treatment effect being significant at $P \leq 0.10$, $P \leq 0.05$ and not significant, respectively.

Table 8. Soil ammonium-N (NH_4-N) and nitrate-N (NO_3-N) concentration in the 0-15, 15-30 and 30-60 cm depths for three termination methods and three termination times for the zero-N treatment in spring 2006 at Star City, Saskatchewan

Stand termination		Concentration of NH_4-N (mg N kg^{-1}) in soil depths (cm)			Concentration of NO_3-N (mg N kg^{-1}) in soil depths (cm)		
Method	Time	0-15	15-30	30-60	0-15	15-30	30-60
				Method x Time			
Herbicide	Cut 1	4.8	5.4	4.1	5.6	4.6	2.6
	Cut 2	4.8	5.2	5.1	6.5	3.8	2.4
	Spring	5.5	6.2	5.7	7.0	4.68	2.6
Tillage	Cut 1	4.6	6.4	4.7	10.2	4.0	2.4
	Cut 2	4.4	5.2	4.3	9.9	3.8	2.7
	Spring	5.3	5.7	5.5	8.4	3.8	2.2
Herbicide + Tillage	Cut 1	5.0	5.6	4.4	8.7	4.0	2.2
	Cut 2	4.1	5.2	4.1	7.3	3.8	2.2
	Spring	5.4	6.0	4.9	9.4	3.6	2.4
	$LSD_{0.05}$	ns	ns	ns	2.3	ns	ns
	SEM	0.31^{ns}	0.57^{ns}	0.33^{ns}	$0.79^{\bullet}$	0.28^{ns}	0.17^{ns}
				Method			
Herbicide		5.1	5.6	4.9	6.4	4.3	2.5
Tillage		4.8	5.8	4.8	9.5	3.9	2.4
Herbicide + Tillage		4.8	5.6	4.5	8.5	3.8	2.3
	$LSD_{0.05}$	ns	ns	ns	1.3	0.5	ns
	SEM	0.18^{ns}	0.33^{ns}	0.19^{ns}	0.46^{***}	$0.16^{\bullet}$	0.10^{ns}
				Time			
	Cut 1	4.8	5.8	4.4	8.2	4.2	2.4
	Cut 2	4.5	5.2	4.5	7.9	3.8	2.4
	Spring	5.4	6.0	5.4	8.3	4.0	2.4
	$LSD_{0.05}$	0.5	ns	0.6	ns	ns	ns
	SEM	0.18^{**}	0.33^{ns}	0.19^{**}	0.46^{ns}	0.16^{ns}	0.10^{ns}

•, **, *** and ns refer to the treatment effect being significant at $P \leq 0.10$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

Table 9a. Soil ammonium-N (NH_4-N) and nitrate-N (NO_3-N) concentration in the 0-15, 15-30 and 30-60 cm depths for two termination methods, three termination times and two N rates in spring 2007 at Star City, Saskatchewan

Treatment			Concentration of NH_4-N (mg N kg^{-1}) in soil depths (cm)			Concentration of NO_3-N (mg N kg^{-1}) in soil depths (cm)		
Termination		N rate						
Method	Time	(kg ha^{-1})	0-15	15-30	30-60	0-15	15-30	30-60
					Method x Time x N Rate			
Herbicide	Cut 1	0	7.6	7.5	6.4	4.4	2.2	2.0
		80	5.6	6.9	6.1	5.9	2.5	2.0
	Cut 2	0	7.1	7.3	6.1	5.8	2.5	1.9
		80	7.3	7.7	6.0	6.7	2.4	1.7
	Spring	0	7.1	6.6	5.9	4.3	2.2	1.8
		80	6.4	7.1	5.8	5.9	2.7	2.2
Tillage	Cut 1	0	5.8	6.7	5.1	3.5	1.9	1.8
		80	6.6	5.9	5.2	5.8	2.4	2.1
	Cut 2	0	7.1	7.9	6.0	4.7	2.2	2.0
		80	5.1	6.2	5.1	4.3	2.5	2.1
	Spring	0	5.7	5.8	5.1	3.6	1.9	19
		80	5.8	6.2	5.4	5.3	2.8	2.9
		$LSD_{0.05}$	ns	ns	ns	ns	ns	ns
		SEM	0.77^{ns}	0.66^{ns}	0.42^{ns}	0.59^{ns}	0.16^{ns}	0.25^{ns}
					Method x Time			
Herbicide	Cut 1		7.1	7.2	6.3	5.2	2.3	2.0
	Cut 2		7.2	7.5	6.0	6.3	2.5	1.8
	Spring		6.8	6.9	5.9	5.1	2.5	2.0
Tillage	Cut 1		6.2	6.3	5.2	4.7	2.1	2.0
	Cut 2		6.1	7.1	5.5	4.5	2.4	2.0
	Spring		5.7	6.0	5.2	4.4	2.4	2.4
		$LSD_{0.05}$	ns	ns	ns	ns	ns	ns
		SEM	0.55^{ns}	0.47^{ns}	0.29^{ns}	0.42^{ns}	0.11^{ns}	0.17^{ns}

ns refers to the treatment effect being not significant.

Table 9b. Soil ammonium-N (NH_4-N) and nitrate-N (NO_3-N) concentration in the 0-15, 15-30 and 30-60 cm depths for two termination methods, three termination times and two N rates in spring 2007 at Star City, Saskatchewan

Treatment		Concentration of NH_4-N (mg N kg^{-1}) in soil depths (cm)			Concentration of NO_3-N (mg N kg^{-1}) in soil depths (cm)		
Method/Time	N Rate kg N ha^{-1}	0-15	15-30	30-60	0-15	15-30	30-60
				Method X N rate			
Herbicide	0	7.3	7.2	6.2	4.8	2.3	1.9
	80	6.8	7.2	6.0	6.2	2.6	2.0
Tillage	0	6.2	6.8	5.4	4.0	2.0	1.9
	80	5.8	6.1	5.2	5.1	2.6	2.4
	$LSD_{0.05}$	ns	ns	ns	ns	ns	ns
	SEM	0.45^{ns}	0.38^{ns}	0.24^{ns}	0.34^{ns}	0.09^{ns}	0.14^{ns}
				Time X N rate			
Cut 1	0	6.7	7.1	5.8	4.0	2.0	1.9
	80	6.6	6.4	5.7	5.9	2.4	2.1
Cut 2	0	7.1	7.6	6.0	5.3	2.4	2.0
	80	6.2	6.9	5.5	5.5	2.5	1.9
Spring	0	6.4	6.2	5.5	4.0	2.1	1.8
	80	6.1	6.7	5.6	3.6	2.8	2.6
	$LSD_{0.05}$	ns	ns	ns	1.2	0.3	0.5
	SEM	0.55^{ns}	0.47^{ns}	0.29^{ns}	0.42•	0.11*	0.17*
				Method			
Herbicide		7.0	7.2	6.1	5.5	2.4	1.9
Tillage		6.0	6.5	5.3	4.5	2.3	2.1
	$LSD_{0.05}$	0.9	0.8	0.5	0.7	ns	ns
	SEM	0.32*	0.27*	0.17**	0.24**	0.07^{ns}	0.10^{ns}
				Time			
Cut 1		6.6	6.7	5.7	4.9	2.2	2.0
Cut 2		6.6	7.3	5.8	5.4	2.4	1.9
Spring		6.2	6.4	5.6	4.8	2.4	2.2
	$LSD_{0.05}$	ns	ns	ns	ns	ns	ns
	SEM	0.39^{ns}	0.33^{ns}	0.21^{ns}	0.30^{ns}	0.08^{ns}	0.12^{ns}
				N rate			
	0	6.7	7.0	5.8	4.4	2.2	1.9
	80	6.3	6.7	5.6	5.6	2.6	2.2
	$LSD_{0.05}$	ns	ns	ns	0.7	0.2	0.3
	SEM	0.32^{ns}	0.27^{ns}	0.17^{ns}	0.24**	0.07***	0.10*

•, *, **, *** and ns refer to the treatment effect being significant at $P \le 0.10$, $P \le 0.05$, $P \le 0.01$, $P \le 0.001$ and not significant, respectively.

Table 10a. Soil ammonium-N (NH_4-N) and nitrate-N (NO_3-N) concentration in the 0-15, 15-30 and 30-60 cm depths for two termination methods, three termination times and four N rates in autumn 2007 at Star City, Saskatchewan

Treatment			Concentration of NH_4-N (mg N kg^{-1}) in soil depths (cm)			Concentration of NO_3-N (mg N kg^{-1}) in soil depths (cm)		
Termination		N rate						
Method	Time	(kg ha^{-1})	0-15	15-30	30-60	0-15	15-30	30-60
					Method x Time x N Rate			
Herbicide	Cut 1	0	5.8	7.2	6.3	2.8	2.1	1.2
		40	4.1	5.6	4.6	4.8	2.2	1.3
		80	5.1	6.4	5.3	4.9	2.0	1.2
		120	6.3	6.2	4.1	7.0	2.6	1.3
	Cut 2	0	4.3	6.2	4.7	3.7	1.5	1.1
		40	6.3	8.1	7.9	4.0	2.0	1.2
		80	6.1	6.1	4.5	5.3	2.1	1.1
		120	2.8	3.6	6.3	6.3	2.1	1.2
	Spring	0	6.2	8.1	6.7	4.6	1.7	1.1
		40	3.2	4.4	3.4	4.5	1.7	1.1
		80	5.1	6.4	4.1	4.8	2.1	1.1
		120	8.5	7.5	8.9	7.9	2.3	1.2
Tillage	Cut 1	0	4.6	6.4	4.8	4.8	1.7	1.0
		40	4.8	5.9	6.0	5.5	2.0	1.2
		80	4.8	6.4	4.8	4.9	1.9	1.1
		120	6.7	6.1	2.9	5.8	2.0	1.0
	Cut 2	0	3.2	4.7	4.9	3.7	1.7	1.2
		40	3.9	6.0	4.7	4.2	1.8	1.1
		80	7.9	7.9	6.6	4.3	2.0	1.1
		120	3.5	4.5	3.4	6.8	2.1	1.2
	Spring	0	5.9	8.1	6.2	3.8	1.7	1.1
		40	8.1	8.5	5.8	5.1	1.8	1.2
		80	5.9	6.7	4.5	5.4	1.7	1.1
		120	5.6	5.5	5.9	6.5	2.1	1.2
		$LSD_{0.05}$	ns	ns	ns	ns	ns	ns
		SEM	1.50^{ns}	1.27^{ns}	1.40^{ns}	0.69^{ns}	0.16^{ns}	0.07^{ns}
					Method x Time			
Herbicide	Cut 1		5.3	6.3	5.1	4.9	2.2	1.2
	Cut 2		4.9	6.0	5.8	4.8	1.9	1.2
	Spring		5.7	6.6	5.8	5.4	2.0	1.1
Tillage	Cut 1		5.2	6.2	4.7	5.2	1.9	1.1
	Cut 2		4.6	5.8	4.9	4.7	1.9	1.1
	Spring		6.4	7.2	5.6	5.2	1.8	1.2
		$LSD_{0.05}$	ns	ns	ns	ns	ns	0.1
		SEM	0.75^{ns}	0.63^{ns}	0.70^{ns}	0.34^{ns}	0.08^{ns}	0.03*

* and ns refer to the treatment effect being significant at $P \leq 0.05$ and not significant, respectively.

Table 10b. Soil ammonium-N (NH_4-N) and nitrate-N (NO_3-N) concentration in the 0-15, 15-30 and 30-60 cm depths for two termination methods, three termination times and four N rates in autumn 2007 at Star City, Saskatchewan

Treatment		Concentration of NH_4-N (mg N kg^{-1}) in soil depths (cm)			Concentration of NO_3-N (mg N kg^{-1}) in soil depths (cm)		
Method/Time	N Rate kg N ha^{-1}	0-15	15-30	30-60	0-15	15-30	30-60
Method X N rate							
Herbicide	0	5.4	7.2	5.9	3.7	1.8	1.2
	40	4.5	6.0	5.3	4.4	2.0	1.2
	80	5.4	6.3	4.7	5.0	2.1	1.1
	120	5.9	5.8	6.4	7.1	2.3	1.2
Tillage	0	4.6	6.4	5.3	4.9	1.7	1.1
	40	5.6	6.8	5.5	4.9	1.9	1.1
	80	6.2	7.0	5.3	4.8	1.9	1.1
	120	5.3	5.4	4.1	6.4	2.1	1.1
	$LSD_{0.05}$	ns	ns	ns	ns	ns	ns
	SEM	0.87^{ns}	0.73^{ns}	0.81^{ns}	0.40^{ns}	0.09^{ns}	0.04^{ns}
Time X N rate							
Cut 1	0	5.2	6.8	5.6	3.8	1.9	1.1
	40	4.5	5.7	5.3	5.1	2.1	1.2
	80	5.0	6.4	5.1	4.9	2.0	1.1
	120	6.5	6.1	3.5	6.4	2.3	1.2
Cut 2	0	3.8	5.4	4.8	3.7	1.6	1.2
	40	5.1	7.0	6.3	4.1	1.9	1.1
	80	7.0	7.0	5.6	4.8	2.0	1.1
	120	3.2	4.1	4.8	6.6	2.1	1.2
Spring	0	6.0	8.1	6.4	4.2	1.7	1.1
	40	5.6	6.4	4.6	4.8	1.7	1.1
	80	5.5	6.5	4.3	5.1	1.9	1.1
	120	7.1	6.5	7.4	7.2	2.2	1.2
	$LSD_{0.05}$	ns	ns	ns	ns	ns	ns
	SEM	1.06^{ns}	0.90^{ns}	0.99^{ns}	0.48^{ns}	0.11^{ns}	0.05^{ns}
Method							
Herbicide		5.3	6.3	5.6	5.1	2.0	1.2
Tillage		5.4	6.4	5.0	5.1	1.9	1.1
	$LSD_{0.05}$	ns	ns	ns	ns	0.1	0.1
	SEM	0.43^{ns}	0.37^{ns}	0.40^{ns}	0.20^{ns}	0.05*	0.02•
Time							
Cut 1		5.3	6.3	4.9	5.0	2.1	1.2
Cut 2		4.8	5.9	5.4	4.8	1.9	1.1
Spring		6.1	6.9	5.7	5.3	1.9	1.1
	$LSD_{0.05}$	ns	ns	ns	ns	0.2	ns
	SEM	0.53^{ns}	0.45^{ns}	0.50^{ns}	0.24^{ns}	0.06•	0.02^{ns}
N rate							
	0	5.0	6.8	5.6	3.9	1.7	1.1
	40	5.1	6.4	5.4	4.7	1.9	1.2
	80	5.8	6.6	5.0	4.9	2.0	1.1
	120	5.6	5.6	5.2	6.7	2.2	1.2
	$LSD_{0.05}$	ns	ns	ns	0.8	0.2	ns
	SEM	0.61^{ns}	0.52^{ns}	0.57^{ns}	0.28***	0.07***	0.03^{ns}
	Linear	0.643^{ns}	0.653^{ns}	0.540^{ns}	0.890*	0.952*	0.124^{ns}
	Quadratic	0.703^{ns}	0.788^{ns}	0.793^{ns}	0.950*	0.956*	0.192^{ns}

•, *, *** and ns refer to the treatment effect being significant at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.001$ and not significant, respectively.

Table 11a. Seed and straw yield, protein and oil concentration in seed, N uptake in seed and straw, and recovery of applied N in seed and straw of canola for three termination methods, three termination times and method x time interaction in 2005 at Star City, Saskatchewan

Stand termination		Seed	Straw	Protein	Oil	N uptake	N uptake	Recovery of applied N	Recovery of applied N
Method	Time	yield (kg ha^{-1})	yield (kg ha^{-1})	conc. (g kg^{-1})	conc. (g kg^{-1})	in seed (kg N ha^{-1})	in straw (kg N ha^{-1})	in seed (%)	in straw (%)
					Method x Time				
Herbicide	Cut 1	2259	4777	212	431	77.9	26.7	42.2	14.3
	Cut 2	2302	4826	214	441	79.8	27.1	37.1	14.0
	Spring	2194	4697	206	449	73.3	26.9	26.9	7.6
Tillage	Cut 1	2231	4726	211	451	76.6	28.9	44.4	15.7
	Cut 2	2230	4733	211	448	76.5	24.8	43.2	10.0
	Spring	2227	4916	207	462	74.7	24.5	43.6	9.1
Herbicide + Tillage	Cut 1	2296	4707	210	453	78.4	25.6	42.8	11.9
	Cut 2	2256	4614	209	461	76.7	24.8	40.3	11.1
	Spring	2207	4609	207	457	74.4	24.4	43.5	8.5
	$LSD_{0.05}$	ns	ns	ns	ns	ns	ns	ns	ns
	SEM	40.7^{ns}	98.0^{ns}	2.4^{ns}	6.6^{ns}	1.88^{ns}	1.03^{ns}	4.04^{ns}	1.92^{ns}
					Method				
Herbicide		2252	4766	211	440	77.0	26.9	35.4	12.0
Tillage		2230	4792	209	459	75.9	25.1	43.7	11.6
Herbicide + Tillage		2253	4670	209	457	76.5	24.9	42.2	10.5
	$LSD_{0.05}$	ns	ns	ns	11	ns	1.7	6.6	ns
	SEM	23.5^{ns}	56.5^{ns}	1.4^{ns}	3.8**	1.08^{ns}	0.59*	2.33*	1.11^{ns}
					Time				
	Cut 1	2262	4737	211	445	77.6	26.1	43.1	14.0
	Cut 2	2263	4724	211	450	77.7	25.6	40.2	11.7
	Spring	2209	4768	207	456	74.2	25.3	38.0	8.4
	$LSD_{0.05}$	66	ns	4	11	3.0	ns	ns	3.1
	SEM	23.5^{ns}	56.5^{ns}	1.4*	$3.8^{•}$	1.08*	0.59^{ns}	2.33^{ns}	1.11**

•, *, ** and ns refer to the treatment effect being significant at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$ and not significant, respectively.

Table 11b. Seed and straw yield, protein and oil concentration in seed, N uptake in seed and straw, and recovery of applied N in seed and straw of canola for four N rates, termination method x N rate interaction and termination time x N rate interaction in 2005 at Star City, Saskatchewan

Treatment: Termination Method/Time	Treatment: N rate ($kg\ ha^{-1}$)	Seed yield ($kg\ ha^{-1}$)	Straw yield ($kg\ ha^{-1}$)	Protein conc. ($g\ kg^{-1}$)	Oil conc. ($g\ kg^{-1}$)	N uptake in seed ($kg\ N\ ha^{-1}$)	N uptake in straw ($kg\ N\ ha^{-1}$)	Recovery of applied N in seed (%)	Recovery of applied N in straw (%)
Method x N Rate									
Herbicide	0	1828	3994	188	440	55.2	19.6		
	40	2133	4692	198	465	67.5	24.0	30.8	11.0
	80	2461	5240	218	431	86.2	29.5	38.7	12.4
	120	2586	5140	239	423	99.1	34.7	36.6	12.6
Tillage	0	1691	3799	184	471	49.8	17.9		
	40	2158	4921	194	469	67.2	22.3	43.6	11.1
	80	2441	5241	217	440	85.6	26.1	44.7	10.2
	120	2628	5206	240	436	101.2	34.0	42.8	13.4
Herbicide + Tillage	0	1725	3799	184	472	50.7	17.8		
	40	2138	4615	194	478	66.1	20.6	38.5	6.9
	80	2485	5020	219	443	86.5	25.6	44.8	9.8
	120	2662	5247	240	435	102.7	35.6	43.3	14.8
$LSD_{0.05}$		ns	ns	ns	ns	ns	ns	ns	ns
SEM		47.0^{ns}	113.0^{ns}	2.7^{ns}	7.6^{ns}	2.17^{ns}	1.19^{ns}	4.04^{ns}	1.92^{ns}
Time x N Rate									
Cut 1	0	1748	3758	184	455	51.7	17.4		
	40	2157	4900	196	467	67.5	22.5	39.7	12.7
	80	2552	5221	221	434	90.6	28.7	48.7	14.0
	120	2591	5068	243	424	100.8	35.6	41.0	15.2
Cut 2	0	1761	3804	188	457	53.2	18.2		
	40	2194	4797	194	465	68.3	22.5	37.6	10.7
	80	2450	5124	221	437	86.9	26.5	42.0	10.3
	120	2646	5172	241	441	102.3	35.1	40.9	14.0
Spring	0	1736	4030	183	470	50.8	19.6		
	40	2077	4531	196	480	65.1	21.9	35.6	5.6
	80	2384	5156	212	442	80.9	26.0	37.5	8.0
	120	2639	5354	236	430	99.9	33.5	40.9	11.6
$LSD_{0.05}$		ns	317	ns	ns	ns	ns	ns	ns
SEM		47.0^{ns}	113.0•	2.7^{ns}	7.6^{ns}	2.17^{ns}	1.19^{ns}	4.04^{ns}	1.92^{ns}
N Rate									
	0	1748	3864	185	461	51.9	18.4		
	40	2143	4743	195	471	67.0	22.3	37.6	9.7
	80	2462	5167	218	438	86.1	27.1	42.7	10.8
	120	2625	5198	240	432	101.0	34.7	40.9	13.6
	$LSD_{0.05}$	76	183	4	12	3.5	1.9	ns	3.1
	SEM	27.1***	65.2***	1.6***	4.4***	1.25***	0.68***	2.33^{ns}	1.11*
	Linear	0.969**	0.845*	0.975**	0.670^{ns}	0.998**	0.976**	0.407^{ns}	0.940*
	Quadratic	0.999**	1.00**	0.995**	0.762^{ns}	0.998**	0.999**	1.00**	1.00**

•, *, **, *** and ns refer to the treatment effect being significant at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

Table 11c. Seed and straw yield, protein and oil concentration in seed, N uptake in seed and straw, and recovery of applied N in seed and straw of canola for termination method x termination time x N rate interaction in 2005 at Star City, Saskatchewan

Treatment										
Termination										
Method	Time	N rate ($kg\ ha^{-1}$)	Seed yield ($kg\ ha^{-1}$)	Straw yield ($kg\ ha^{-1}$)	Protein ($g\ kg^{-1}$)	Oil conc. ($g\ kg^{-1}$)	N uptake in seed ($kg\ ha^{-1}$)	N uptake in straw ($kg\ ha^{-1}$)	Recovery of applied N in seed (%)	Recovery of applied N in straw (%)
							Method x Time x N Rate			
Herbicide	Cut 1	0	1771	3830	187	423	53.3	18.1		
		40	2204	4785	200	458	70.4	23.2	42.7	12.7
		80	2558	5499	223	423	91.7	31.7	48.1	17.0
		120	2505	4993	240	419	96.2	33.9	35.8	13.2
	Cut 2	0	1882	4017	190	443	57.6	19.2		
		40	2286	5190	200	455	72.8	26.3	38.2	18.0
		80	2411	4977	222	434	85.8	27.2	35.4	10.1
		120	2631	5119	244	433	102.8	35.8	37.8	13.9
	Spring	0	1832	4134	187	454	54.8	21.5		
		40	1908	4100	195	482	59.4	22.4	11.6	2.2
		80	2414	5245	210	436	81.0	29.5	32.8	10.0
		120	2621	5308	233	424	98.2	34.2	36.2	10.6
Tillage	Cut 1	0	1679	3654	185	467	49.8	16.7		
		40	2159	5132	193	461	66.8	24.0	42.4	18.3
		80	2500	5083	218	439	87.0	25.8	46.5	11.5
		120	2587	5036	248	438	102.8	37.4	44.2	17.3
	Cut 2	0	1678	3562	186	454	50.0	18.0		
		40	2114	4697	192	465	64.9	20.2	37.1	5.5
		80	2479	5359	226	435	89.6	26.7	49.5	10.9
		120	2650	5314	239	439	101.6	34.4	42.9	13.7
	Spring	0	1717	4182	180	491	49.5	19.1		
		40	2202	4935	198	480	70.0	22.9	51.2	9.6
		80	2343	5280	214	446	80.1	25.7	38.3	8.3
		120	2646	5269	234	431	99.2	30.2	41.4	9.3
Herbicide + Tillage	Cut 1	0	1794	3789	181	454	51.9	17.6		
		40	2108	4784	195	482	65.4	20.5	33.9	7.2
		80	2598	5082	223	440	93.0	28.5	51.4	13.6
		120	2681	5174	240	417	103.4	35.7	43.0	15.0
	Cut 2	0	1723	3835	189	475	52.1	17.6		
		40	2184	4504	192	474	67.1	21.0	37.6	8.6
		80	2461	5035	216	444	85.1	25.6	41.3	10.0
		120	2656	5082	240	451	102.5	35.0	42.0	14.6
	Spring	0	1659	3773	182	466	48.2	18.3		
		40	2122	4557	194	480	65.8	20.3	44.0	5.0
		80	2396	4944	212	445	81.5	22.9	41.6	5.7
		120	2651	5486	241	437	102.3	36.1	45.1	14.9
		$LSD_{0.05}$	ns	549	ns	ns	ns	ns	ns	ns
		SEM	81.4^{ns}	$195.8^{\bullet}$	4.7^{ns}	13.1^{ns}	3.75^{ns}	2.06^{ns}	6.99^{ns}	3.33^{ns}

$^{\bullet}$ and ns refer to the treatment effect being significant at $P \leq 0.10$ and not significant, respectively.

Table 12a. Seed and straw yield, protein concentration in seed, N uptake in seed and straw, recovery of applied N in seed and straw of wheat for three termination methods, three termination times and method x time interaction in 2006 at Star City, Saskatchewan

Stand termination Method	Time	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Protein (g kg^{-1})	N uptake in seed (kg N ha^{-1})	N uptake in straw (kg N ha^{-1})	Recovery of applied N in seed (%)	Recovery of applied N in straw (%)
					Method x Time			
Herbicide	Cut 1	2745	3979	154	73.0	18.3	48.8	15.2
	Cut 2	2806	4071	157	76.1	18.4	48.5	13.5
	Spring	2731	3854	159	74.9	18.8	45.9	14.2
Tillage	Cut 1	2915	4201	156	78.5	20.6	48.7	14.1
	Cut 2	2894	4192	159	79.3	20.9	43.3	11.6
	Spring	2989	4288	157	80.8	20.9	48.8	12.7
Herbicide + Tillage	Cut 1	2940	4128	154	78.3	19.6	41.2	11.3
	Cut 2	2943	4204	158	79.9	21.5	44.1	15.6
	Spring	2932	4224	156	79.1	21.1	46.1	13.0
	$LSD_{0.05}$	ns	ns	ns	ns	ns	ns	3.1
	SEM	39.0^{ns}	74.0^{ns}	1.7^{ns}	1.11^{ns}	0.56^{ns}	2.76^{ns}	1.09*
					Method			
Herbicide		2760	3968	157	74.7	18.5	47.7	14.3
Tillage		2933	4227	157	79.5	20.8	46.9	12.8
Herbicide + Tillage		2939	4204	156	79.1	20.8	43.8	13.3
	$LSD_{0.05}$	63	120	ns	1.8	0.9	ns	ns
	SEM	22.6***	42.7***	1.0^{ns}	0.64***	0.32***	1.59^{ns}	0.63^{ns}
					Time			
	Cut 1	2867	4121	155	76.6	19.5	46.2	13.5
	Cut 2	2881	4156	158	78.4	20.3	45.3	13.5
	Spring	2884	4122	157	78.3	20.3	46.9	13.3
	$LSD_{0.05}$	ns	ns	3	1.8	ns	ns	ns
	SEM	22.6^{ns}	42.7^{ns}	$1.0^{\bullet}$	$0.64^{\bullet}$	0.32^{ns}	1.59^{ns}	0.63^{ns}

•, *, *** and ns refer to the treatment effect being significant at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.001$ and not significant, respectively.

Table 12b. Seed and straw yield, protein concentration in seed, N uptake in seed and straw, recovery of applied N in seed and straw of wheat for four N rates, termination method x N rate interaction and termination time x N rate interaction in 2006 at Star City, Saskatchewan

Treatment								
Termination Method/Time	N rate (kg ha^{-1})	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Protein conc. (g kg^{-1})	N uptake in seed (kg N ha^{-1})	N uptake in straw (kg N ha^{-1})	Recovery of applied N in seed (%)	Recovery of applied N in straw (%)
					Method x N Rate			
Herbicide	0	1962	2693	140	46.9	10.0		
	40	2693	3963	146	66.7	15.8	49.6	14.4
	80	3195	4599	163	88.6	21.9	52.1	14.9
	120	3192	4618	178	96.5	26.3	41.4	13.6
Tillage	0	2257	3301	137	52.5	13.0		
	40	2939	4197	147	73.6	17.7	52.6	11.7
	80	3211	4627	166	90.5	24.2	47.4	13.9
	120	3325	4782	179	101.5	28.3	40.8	12.7
Herbicide + Tillage	0	2258	3246	138	53.2	12.7		
	40	2844	4143	147	70.9	17.9	44.2	12.9
	80	3259	4644	164	90.9	23.8	47.1	13.9
	120	3394	4780	175	101.3	28.5	40.0	13.2
$LSD_{0.05}$		127	240	ns	ns	ns	ns	ns
SEM		45.1*	85.5*	1.9^{ns}	1.28^{ns}	0.65^{ns}	2.76^{ns}	1.09^{ns}
					Time x N Rate			
Cut 1	0	2109	3054	138	49.8	11.3		
	40	2830	4107	144	69.2	16.3	48.5	12.6
	80	3267	4659	162	90.2	22.8	50.5	14.4
	120	3262	4664	176	97.4	27.7	39.7	13.7
Cut 2	0	2189	3084	139	51.8	12.1		
	40	2806	4096	147	70.3	17.1	46.4	12.6
	80	3190	4598	166	90.3	23.4	48.1	14.2
	120	3340	4845	178	101.4	28.6	41.3	13.8
Spring	0	2180	3103	138	51.1	12.5		
	40	2839	4101	148	71.8	18.0	51.6	13.8
	80	3207	4613	164	89.6	23.7	48.0	14.1
	120	3310	4671	179	100.6	26.9	41.2	12.0
$LSD_{0.05}$		ns	ns	ns	ns	ns	ns	ns
SEM		45.1^{ns}	85.5^{ns}	1.9^{ns}	1.28^{ns}	0.65^{ns}	2.76^{ns}	1.09^{ns}
					N Rate			
	0	2159	3080	138	50.9	11.9		
	40	2825	4101	146	70.4	17.1	48.8	13.0
	80	3222	4623	164	90.0	23.3	48.9	14.2
	120	3304	4727	177	99.8	27.7	40.7	13.2
	$LSD_{0.05}$	73	138	3	2.1	1.1	4.5	ns
	SEM	26.0***	49.4***	1.1***	0.74***	0.38***	1.59***	0.63^{ns}
	Linear	0.896*	0.876^{ns}	0.981**	0.980**	0.996**	0.741^{ns}	0.024^{ns}
	Quadratic	1.00**	1.00**	0.988*	0.997**	0.997**	1.00**	1.00**

*, **, *** and ns refer to the treatment effect being significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

Table 12c. Seed and straw yield, protein concentration in seed, N uptake in seed and straw, recovery of applied N in seed and straw of wheat for termination method x termination time x N rate interaction in 2006 at Star City, Saskatchewan

Treatment: Termination Method	Treatment: Termination Time	N rate (kg N ha^{-1})	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Protein conc. (g kg^{-1})	N uptake in seed (kg N ha^{-1})	N uptake in straw (kg N ha^{-1})	Recovery of applied N in seed (%)	Recovery of applied N in straw (%)
						Method x Time x N Rate			
Herbicide	Cut 1	0	1889	2637	140	45.2	9.1		
		40	2728	3994	142	66.0	15.0	52.1	14.8
		80	3267	4752	162	90.3	21.7	56.4	15.7
		120	3095	4534	172	90.6	27.2	37.8	15.1
	Cut 2	0	2059	2885	135	47.7	10.5		
		40	2727	4030	147	68.1	16.3	51.0	14.4
		80	3139	4556	165	87.9	21.5	50.3	13.8
		120	3298	4812	179	100.7	25.2	44.1	12.3
	Spring	0	1939	2557	144	47.8	10.3		
		40	2623	3865	148	66.0	16.0	45.7	14.0
		80	3180	4488	162	87.5	22.5	49.7	15.2
		120	3182	4508	182	98.3	26.5	42.2	13.5
Tillage	Cut 1	0	2186	3241	136	50.6	12.2		
		40	2969	4264	144	72.6	17.8	54.9	13.9
		80	3294	4710	161	90.4	24.2	49.7	15.0
		120	3210	4590	184	100.4	28.3	41.5	13.4
	Cut 2	0	2274	3273	138	53.5	13.6		
		40	2792	3960	148	70.5	17.0	42.4	8.5
		80	3172	4611	170	91.4	24.1	47.4	13.2
		120	3340	4922	179	101.6	29.1	40.1	13.0
	Spring	0	2310	3390	136	53.5	13.3		
		40	3055	4369	149	77.6	18.4	60.3	12.7
		80	3166	4559	167	89.6	24.2	45.2	13.5
		120	3425	4832	176	102.4	27.5	40.8	11.8
Herbicide + Tillage	Cut 1	0	2252	3285	139	53.5	12.5		
		40	2791	4062	145	68.8	16.1	38.4	9.1
		80	3240	4514	163	89.7	22.4	45.3	12.4
		120	3479	4868	171	101.2	27.5	39.8	12.5
	Cut 2	0	2233	3092	142	54.1	12.1		
		40	2900	4297	146	72.3	18.0	45.7	14.9
		80	3260	4628	165	91.4	24.5	46.8	15.6
		120	3380	4801	177	101.8	31.5	39.8	16.3
	Spring	0	2290	3362	134	52.2	13.7		
		40	2840	4070	149	71.7	19.5	48.7	14.6
		80	3276	4791	164	91.5	24.6	49.2	13.6
		120	3323	4673	178	100.9	26.6	40.6	10.8
		$LSD_{0.05}$	ns	ns	ns	ns	ns	ns	ns
		SEM	78.1^{ns}	148.0^{ns}	3.3^{ns}	2.22^{ns}	1.13^{ns}	4.78^{ns}	1.89^{ns}

ns refers to the treatment effect being not significant.

Table 13a. Seed and straw yield, protein and oil concentration in seed, N uptake in seed and straw, and recovery of applied N in seed and straw of canola for three termination methods, three termination times and method x time interaction in 2007 at Star City, Saskatchewan

Stand termination		Seed	Straw	Protein	Oil	N uptake	N uptake	Recovery of applied N	Recovery of applied
Method	Time	yield ($kg\ ha^{-1}$)	yield ($kg\ ha^{-1}$)	conc. ($g\ kg^{-1}$)	conc. ($g\ kg^{-1}$)	in seed ($kg\ N\ ha^{-1}$)	in straw ($kg\ N\ ha^{-1}$)	in seed (%)	N in straw (%)
					Method x Time				
Herbicide	Cut 1	1686	3542	191	514	52.4	18.3	41.4	14.53
	Cut 2	1646	3290	190	517	51.1	16.3	35.9	12.0
	Spring	1706	3563	192	514	53.3	17.8	36.3	12.6
Tillage	Cut 1	1684	3398	192	514	52.7	17.1	39.4	13.3
	Cut 2	1689	3553	192	512	52.1	17.3	38.6	9.7
	Spring	1737	3554	191	514	54.0	17.2	38.7	9.7
Herbicide + Tillage	Cut 1	1707	3558	190	515	52.9	18.4	32.2	11.5
	Cut 2	1716	3595	197	512	54.6	19.5	39.4	16.1
	Spring	1728	3554	193	514	54.4	18.2	38.4	15.4
	$LSD_{0.05}$	ns	228	4	3	ns	1.8	6.9	3.8
	SEM	27.9^{ns}	$81.4^{\bullet}$	$1.4^{\bullet}$	$1.2^{\bullet}$	0.97^{ns}	$0.64^{\bullet}$	$2.46^{\bullet}$	1.33^{*}
					Method				
Herbicide		1680	3465	191	515	52.3	17.5	37.9	13.0
Tillage		1703	3502	192	513	53.1	17.2	38.9	10.9
Herbicide + Tillage		1717	3569	193	513	54.0	18.7	36.7	14.3
	$LSD_{0.05}$	ns	ns	ns	2	1.6	1.0	ns	2.2
	SEM	16.1^{ns}	17.0^{ns}	0.8^{ns}	0.7^{ns}	$0.56^{\bullet}$	0.37^{*}	1.42^{ns}	0.77^{**}
					Time				
	Cut 1	1692	3499	191	514	52.6	17.9	37.7	13.1
	Cut 2	1684	3480	193	514	52.8	17.7	38.0	12.6
	Spring	1724	3557	192	514	53.9	17.8	37.8	12.6
	$LSD_{0.05}$	ns	ns	ns	2	ns	ns	ns	ns
	SEM	16.1^{ns}	17.0^{ns}	0.8^{ns}	0.7^{ns}	0.56^{ns}	0.37^{ns}	1.42^{ns}	0.77^{ns}

$^{\bullet}$, *, ** and ns refer to the treatment effect being significant at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$ and not significant, respectively.

Table 13b. Seed and straw yield, protein and oil concentration in seed, N uptake in seed and straw, and recovery of applied N in seed and straw of canola for four N rates, termination method x N rate interaction and termination time x N rate interaction in 2007 at Star City, Saskatchewan

Treatment		Seed yield	Straw yield	Protein conc.	Oil conc.	N uptake in seed	N uptake in straw	Recovery of applied N in seed	Recovery of applied N in straw
Termination Method/Time	N rate (kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(g kg^{-1})	(g kg^{-1})	(kg N ha^{-1})	(kg N ha^{-1})	(%)	(%)
					Method x N Rate				
Herbicide	0	1006	2062	180	530	29.1	9.3		
	40	1521	3335	175	529	42.6	13.8	34.0	11.0
	80	2028	4260	190	514	61.8	20.6	40.9	14.0
	120	2164	4203	218	487	75.6	26.2	38.8	14.0
Tillage	0	1056	2140	178	531	30.1	10.3		
	40	1611	3427	179	528	46.1	13.6	39.9	8.3
	80	2026	4270	192	510	62.3	20.3	40.2	12.5
	120	2120	4170	219	484	74.1	24.6	39.7	12.0
Herbicide + Tillage	0	1100	2156	180	532	31.5	10.1		
	40	1566	3527	178	528	44.7	15.7	32.8	14.0
	80	2035	4335	195	509	63.6	22.1	40.0	15.0
	120	2167	4259	219	485	76.0	26.9	37.1	14.0
LSD$_{0.05}$		ns	ns	ns	ns	ns	ns	ns	ns
SEM		32.2^{ns}	94.0^{ns}	1.7^{ns}	1.4^{ns}	1.12^{ns}	0.74^{ns}	2.46^{ns}	1.33^{ns}
					Time x N Rate				
Cut 1	0	1036	2071	179	532	29.6	9.7		
	40	1542	3413	174	529	42.9	13.8	33.2	10.2
	80	2075	4291	193	509	64.0	22.1	42.9	15.5
	120	2118	4222	219	486	74.0	26.0	37.0	13.6
Cut 2	0	1040	2118	179	530	29.8	9.8		
	40	1542	3420	179	529	44.1	14.0	35.8	10.6
	80	1992	4261	193	511	61.7	20.3	39.8	13.1
	120	2160	4120	219	485	75.8	26.8	38.3	14.1
Spring	0	1086	2169	180	531	31.3	10.3		
	40	1614	3456	180	527	43.4	15.3	37.8	12.6
	80	2022	4314	191	513	62.0	20.6	38.5	12.9
	120	2173	4289	218	484	75.9	24.9	37.2	12.2
LSD$_{0.05}$		ns	ns	ns	ns	ns	ns	ns	ns
SEM		32.2^{ns}	94.0^{ns}	1.7^{ns}	1.4^{ns}	1.12^{ns}	0.74^{ns}	2.46^{ns}	1.33^{ns}
					N Rate				
	0	1054	2119	179	531	30.2	9.9		
	40	1566	3430	177	528	44.5	14.4	35.6	11.1
	80	2030	4288	192	511	62.5	21.0	40.4	13.9
	120	2150	4210	219	485	75.2	25.9	37.5	13.3
	LSD$_{0.05}$	52	152	3	2	1.8	1.2	4.0	2.2
	SEM	18.6***	54.3***	1.0***	0.8***	0.65***	0.43***	1.42•	0.77*
	Linear	0.943*	0.837^{ns}	0.812^{ns}	0.900	0.996**	0.995**	0.162^{ns}	0.578^{ns}
	Quadratic	0.994**	0.996**	0.999**	0.999	0.996**	0.995**	1.00**	1.00**

•, *, **, *** and ns refer to the treatment effect being significant at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

Table 13c. Seed and straw yield, protein and oil concentration in seed, N uptake in seed and straw, and recovery of applied N in seed and straw of canola for termination method x termination time x N rate interaction in 2007 at Star City, Saskatchewan

Treatment: Method	Termination Time	N rate (kg ha^{-1})	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Protein conc. (g kg^{-1})	Oil conc. (g kg^{-1})	N uptake in seed (kg ha^{-1})	N uptake in straw (kg ha^{-1})	Recovery of applied N in seed (%)	Recovery of applied N in straw (%)
						Method x Time x N Rate				
Herbicide	Cut 1	0	950	2087	180	531	23.4	9.1		
		40	1522	3349	175	528	42.7	13.6	38.3	11.2
		80	2424	4388	189	510	64.2	22.6	46.0	16.9
		120	2149	4341	219	485	75.2	27.7	39.9	15.5
	Cut 2	0	1022	1864	175	532	28.6	8.5		
		40	1446	3208	175	532	40.5	12.1	29.7	8.8
		80	1945	4046	193	514	59.9	18.6	39.1	12.5
		120	2170	4043	217	490	75.5	26.0	39.1	14.6
	Spring	0	1044	2234	186	527	31.2	10.4		
		40	1595	3449	176	527	44.7	15.6	33.9	13.1
		80	2014	4345	190	517	61.3	20.5	37.7	12.7
		120	2172	4224	218	485	76.0	24.8	37.3	12.1
Tillage	Cut 1	0	1023	1855	179	533	29.5	8.9		
		40	1609	3481	177	529	45.4	13.6	39.9	11.7
		80	2048	4066	195	510	63.9	20.8	43.1	14.9
		120	2056	4191	219	483	72.0	24.9	35.4	13.4
	Cut 2	0	1052	2383	177	528	29.8	11.0		
		40	1574	3450	180	527	45.2	13.6	38.6	6.4
		80	2018	4283	192	510	62.0	20.2	40.3	11.5
		120	2113	4095	220	484	74.2	24.6	37.0	11.4
	Spring	0	1094	2182	178	533	31.1	11.0		
		40	1652	3349	180	527	47.6	13.7	41.2	6.7
		80	2011	4461	189	512	60.9	20.0	37.2	11.2
		120	2192	4224	217	484	76.2	24.4	37.6	11.2
Herbicide + Tillage	Cut 1	0	1133	2269	177	532	32.1	11.1		
		40	1495	3410	169	529	40.6	14.2	21.3	7.7
		80	2052	4418	194	508	63.8	23.0	39.6	14.9
		120	2148	4134	218	489	75.0	25.3	35.8	11.9
	Cut 2	0	1045	2107	186	530	31.0	9.9		
		40	1606	3602	182	527	46.7	16.5	39.1	16.5
		80	2013	4452	196	510	63.0	22.2	40.0	15.4
		120	2198	4221	221	482	77.7	29.7	38.9	16.5
	Spring	0	1121	2091	176	533	31.5	9.4		
		40	1597	3570	183	527	46.7	16.6	38.1	17.9
		80	2040	4135	195	509	63.9	21.2	40.5	14.8
		120	2155	4421	219	484	75.4	25.6	36.6	13.5
		$LSD_{0.05}$	ns	ns	ns	ns	ns	ns	ns	ns
		SEM	55.8^{ns}	162.8^{ns}	2.9^{ns}	2.4^{ns}	1.94^{ns}	1.28^{ns}	4.25^{ns}	2.31^{ns}

ns refers to the treatment effect being not significant.

Table 14. Estimated cumulative N_2O-N emissions for termination methods, termination times and method x time interaction in 2004, 2005 and 2006 at Star City, Saskatchewan

Stand Termination		N_2O-N loss (g N ha^{-1})		
Method	Time	2004	2005	2006
			Method x Time	
Herbicide	Cut 1	220	460	150
	Cut 2	260	670	155
	Spring	240	730	180
Tillage	Cut 1	280	510	247
	Cut 2	400	420	329
	Spring	420	330	170
Herbicide + Tillage	Cut 1	290	410	221
	Cut 2	310	470	263
	Spring	300	440	181
	$LSD_{0.05}$	ns	ns	ns
	SEM	57.4^{ns}	100.7^{ns}	45.7^{ns}
			Method	
Herbicide		240	620	249
Tillage		370	420	162
Herbicide + Tillage		300	440	222
	$LSD_{0.05}$	96	168	76
	SEM	33.2*	58.3*	$26.3^{•}$
			Time	
	Cut 1	260	460	206
	Cut 2	320	520	249
	Spring	320	500	177
	$LSD_{0.05}$	ns	ns	ns
	SEM	33.2^{ns}	58.3^{ns}	26.3^{ns}

•, *, and ns refer to the treatment effect being significant at $P \leq 0.10$, $P \leq 0.05$ and not significant, respectively.

Table 15. Estimated cumulative N_2O-N emissions for termination methods, termination times, N rate and their interactions in 2007 at Star City, Saskatchewan

Termination method	Termination time	N_2O-N loss (g N ha^{-1})			
		Method x Time x N rate			
		0 kg N ha^{-1}	80 kg N ha^{-1}	$LSD_{0.05}$	SEM
Herbicide	Cut 1	425	420	ns	102.1^{ns}
	Cut 2	220	673		
	Spring	309	371		
Tillage	Cut 1	259	849		
	Cut 2	273	647		
	Spring	261	499		
		Method x N rate			
Herbicide		318	418	ns	61.9^{ns}
Tillage		264	665		
		Time x N rate			
	Cut 1	342	634	ns	72.3^{ns}
	Cut 2	246	660		
	Spring	285	435		
		Method x Time			
		Herbicide	Tillage		
	Cut 1	422	554	ns	72.3^{ns}
	Cut 2	446	460		
	Spring	340	380		
		N rate			
		0 kg N ha^{-1}	80 kg N ha^{-1}		
		291	576	120***	41.5***
		Method			
		Herbicide	Tillage		
		403	464	ns	41.5^{ns}
		Time			
	Cut 1	488		ns	51.2^{ns}
	Cut 2	453			
	Spring	360			

*** and ns refer to the treatment effect being significant at $P \leq 0.001$ and not significant, respectively.

Table 16. Effect of alfalfa termination method, termination time and N rate on the amount of total organic C (TOC) and total organic N (TON) in 0-5, 5-10, 10-15 and 0-15 cm soil in autumn 2007 at Star City in northeastern Saskatchewan

Treatment		Amount of TOC (Mg C ha^{-1}) in soil layers (cm)				Amount of TON (Mg N ha^{-1}) in soil layers (cm)			
Method/Time	N Rate kg N ha^{-1}	0-5	5-10	10-15	0-15	0-5	5-10	10-15	0-15
						Method			
Herbicide		16.4	13.9	12.3	42.5	1.35	1.21	1.12	3.69
Tillage		14.2	14.9	12.7	41.8	1.16	1.29	1.14	3.59
	$LSD_{0.05}$	0.8	0.6	ns	ns	0.06	0.05	ns	ns
	SEM	0.28^{***}	0.20^{***}	0.40^{ns}	0.71^{ns}	0.020^{**}	0.017^{**}	0.028^{ns}	0.051^{ns}
						Time			
Cut 1		15.7	14.7	12.6	43.0	1.29	1.27	1.13	3.69
Cut 2		15.5	14.4	12.6	42.5	1.27	1.25	1.14	3.66
Spring		14.7	14.1	12.2	41.0	1.22	1.23	1.12	3.57
	$LSD_{0.05}$	1.0	ns	ns	ns	0.07	ns	ns	ns
	SEM	$0.34^{\bullet}$	0.24^{ns}	0.49^{ns}	0.87^{ns}	$0.024^{\bullet}$	0.020^{ns}	0.035^{ns}	0.062^{ns}
						N rate			
	0	14.8	14.3	12.7	41.8	1.23	1.25	1.14	3.62
	80	15.8	14.5	12.3	42.5	1.29	1.25	1.12	3.66
	$LSD_{0.05}$	0.8	ns	ns	ns	0.06	ns	ns	ns
	SEM	0.28^{*}	0.20^{ns}	0.40^{ns}	0.71^{ns}	0.020^{*}	0.017^{ns}	0.028^{ns}	0.051^{ns}

•, *, **, *** and ns refer to the treatment effect being significant at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

Table 17. Effect of alfalfa termination method, termination time and N rate on the amount of light fraction organic matter (LFOM), light fraction organic C (LFOC and light fraction organic N(LFON) in 0-5, 5-10, 10-15 and 0-15 cm soil layers in autumn 2007 at Star City in northeastern Saskatchewan

Treatment		Amount of LFOM (Mg ha^{-1}) in soil layers (cm)				Amount of LFOC (Mg C ha^{-1}) in soil layers (cm)				Amount of LFON (Mg N ha^{-1}) in soil layers (cm)			
Method/Time	N Rate kg N ha^{-1}	0-5	5-10	10-15	0-15	0-5	5-10	10-15	0-15	0-5	5-10	10-15	0-15
								Method X N rate					
Herbicide	0	13.3	5.33	2.94	21.5	3.43	1.09	0.685	5.21	0.220	0.068	0.035	0.322
	80	13.2	5.07	2.43	20.7	3.38	1.08	0.569	5.03	0.214	0.065	0.032	0.310
Tillage	0	9.8	7.18	3.41	20.4	2.35	1.54	0.769	4.66	0.133	0.093	0.041	0.267
	80	12.0	7.44	3.81	23.2	2.86	1.61	0.781	5.25	0 156	0.105	0.044	0.305
	$LSD_{0.05}$	ns	ns	ns	ns	ns	ns	ns	0.60	ns	ns	ns	0.040
	SEM	0.88^{ns}	0.410^{ns}	0.308^{ns}	1.16^{ns}	0 181^{ns}	0.078^{ns}	0.0589^{ns}	0.207$^{\bullet}$	0.0114^{ns}	0.0049^{ns}	0.0032^{ns}	0.0139$^{\bullet}$
								Time X N rate					
Cut 1	0	10.4	6.26	3.04	19.7	2.59	1.31	0.720	4.62	0.160	0.081	0.036	0.277
	80	14.1	6.66	3.29	24.1	3 47	1.40	0.737	5 61	0.204	0.088	0.041	0.333
Cut 2	0	12.6	6.51	3.64	22.7	3.26	1.39	0.793	5.45	0.198	0.082	0.041	0.321
	80	12.5	5.78	3.23	21.5	3.20	1.32	0.650	5.17	0.194	0.083	0.037	0.314
Spring	0	11.6	6.00	2.84	20.5	2.83	i 25	0.669	4.75	1.172	0.078	0.036	0.286
	80	11.2	6.32	2.84	20.4	2.68	1.32	0.638	4.64	0.157	0.082	0.037	0.276
	$LSD_{0.05}$	ns	ns	ns	ns	0.64	ns	ns	0.73	0.040	ns	ns	0.049
	SEM	1.08^{ns}	0.503^{ns}	0.337^{ns}	1.42^{ns}	0.222*	0.095^{ns}	0.0721^{ns}	0.0254*	0.0140$^{\bullet}$	0.0061^{ns}	0.0039^{ns}	0.0170$^{\bullet}$
								Method					
Herbicide		13.2	5.20	2.69	21.1	3.41	1.09	0.627	5.12	0.217	0.066	0.033	0.316
Tillage		10.9	7.31	3.61	21.8	2.61	1 57	0.775	4.96	0.145	0.099	0.042	0.287
	$LSD_{0.05}$	1.8	0.84	0.63	ns	0.37	0.16	0.120	ns	0.023	0.010	0.007	0.028
	SEM	0.62*	0.290***	0.218**	0.82^{ns}	0.128***	0.055***	0.0416*	0.146^{ns}	0.0081***	0.0035***	0.0023**	0.0098*
								Time					
Cut 1		12.3	6.46	3.17	21.9	3.03	1.36	0.728	5.11	0.182	0.085	0.038	0.305
Cut 2		12.5	6.14	3.44	22.1	2.23	1.35	0.721	5.31	0.196	0.083	0.039	0.317
Spring		11.4	6.16	2.84	20.4	2.76	1.28	0.653	4.69	0.164	0.080	0.036	0.280
	$LSD_{0.05}$	ns	ns	ns	ns	0.45	ns	ns	0.52	0.029	ns	ns	0.035
	SEM	0.76^{ns}	0.355^{ns}	0.267^{ns}	1.00^{ns}	0.157$^{\bullet}$	0 067^{ns}	0.051^{ns}	0.179*	0.0099$^{\bullet}$	0.0043^{ns}	0.0028^{ns}	0.0120$^{\bullet}$
								N rate					
	0	11.5	6.26	3.18	21.0	2.89	1.32	0.727	4.94	0.176	0.080	0.038	0 295
	80	12.6	6.25	3.12	22.0	3.12	1 35	0.675	5.14	0.185	0.085	0.038	0.308
	$LSD_{0.05}$	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	SEM	0.62^{ns}	0.290^{ns}	0.218^{ns}	0.82^{ns}	0.128^{ns}	0.055^{ns}	0.0416^{ns}	0 146^{ns}	0.0081^{ns}	0.0035^{ns}	0.0023^{ns}	0.0098^{ns}

$^{\bullet}$, *, **, *** and ns refer to the treatment effect being significant at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

APPENDICES

Appendix 1.

Appendix 1a. Thousand seed weight (TSW) of wheat in 2004, canola in 2005, wheat in 2006 and canola in 2007 for three termination methods, three termination times and method x time interaction at Star City, Saskatchewan

Stand termination		TSW (g)			
Method	Time	2004 Wheat	2005 Canola	2006 Wheat	2007 Canola
			Method x Time		
Herbicide	Cut 1	29.2	3.5	32.5	3.1
	Cut 2	29.7	3.5	32.8	3.1
	Spring	29.9	3.5	32.3	3.2
Tillage	Cut 1	32.4	3.5	32.2	3.2
	Cut 2	32.6	3.5	32.5	3.2
	Spring	31.7	3.4	32.7	3.1
Herbicide + Tillage	Cut 1	33.6	3.5	32.2	3.1
	Cut 2	32.5	3.5	32.4	3.2
	Spring	30.8	3.4	31.8	3.0
	$LSD_{0.05}$	1.3	ns	0.7	0.1
	SEM	0.45**	0.03^{ns}	0.24^{ns}	0.03**
			Method		
Herbicide		29.6	3.5	32.5	3.1
Tillage		32.2	3.4	32.4	3.2
Herbicide + Tillage		32.3	3.5	32.2	3.1
	$LSD_{0.05}$	0.7	0.1	ns	0.1
	SEM	0.26***	0.02*	0.14^{ns}	0.02**
			Time		
	Cut 1	31.7	3.5	32.3	3.1
	Cut 2	31.6	3.5	32.6	3.2
	Spring	30.8	3.5	32.2	3.1
	$LSD_{0.05}$	0.7	ns	ns	ns
	SEM	0.26*	0.02^{ns}	0.14^{ns}	0.02^{ns}

*, **, *** and ns refer to the treatment effect being significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

Appendix 1b. Thousand seed weight (TSW) of wheat in 2004, canola in 2005, wheat in 2006 and canola in 2007 for four N rates, termination method x N rate interaction and termination time x N rate interaction in 2007 at Star City, Saskatchewan

Treatment		TSW (g)			
Termination Method/Time	N rate (kg ha^{-1})	2004 Wheat	2005 Canola	2006 Wheat	2007 Canola
		Method x N Rate			
Herbicide	0	26.0	3.5	30.9	3.2
	40	28.0	3.6	32.1	3.0
	80	32.3	3.4	33.4	3.1
	120	32.2	3.5	33.7	3.2
Tillage	0	30.4	3.4	30.8	3.2
	40	32.0	3.4	32.3	3.1
	80	33.1	3.4	33.5	3.2
	120	33.4	3.4	33.2	3.2
Herbicide + Tillage	0	31.0	3.5	30.7	3.1
	40	31.3	3.5	32.0	3.0
	80	33.3	3.5	33.0	3.1
	120	33.6	3.4	32.9	3.2
$LSD_{0.05}$		1.5	ns	ns	ns
SEM		0.52***	0.04^{ns}	0.28^{ns}	0.03^{ns}
		Time x N Rate			
Cut 1	0	29.8	3.5	30.8	3.2
	40	30.9	3.5	32.0	3.0
	80	33.2	3.5	33.4	3.1
	120	33.0	3.4	33.0	3.2
Cut 2	0	29.2	3.5	31.0	3.2
	40	31.5	3.5	31.9	3.1
	80	32.8	3.4	33.7	3.1
	120	32.9	3.5	33.8	3.2
Spring	0	28.3	3.5	30.7	3.2
	40	28.9	3.5	32.4	3.1
	80	32.8	3.4	32.9	3.1
	120	33.3	3.4	33.0	3.2
$LSD_{0.05}$		1.5	ns	ns	ns
SEM		0.52•	0.04^{ns}	0.28^{ns}	0.03^{ns}
		N Rate			
	0	29.1	3.5	30.8	3.2
	40	30.4	3.5	32.1	3.0
	80	32.9	3.4	33.3	3.1
	120	33.1	3.4	33.3	3.2
	$LSD_{0.05}$	0.8	0.1	0.5	0.1
	SEM	0.30***	0.02^{ns}	0.16***	0.02***
	Linear	0.920*	0.769^{ns}	0.887*	0.027^{ns}
	Quadratic	0.946*	0.808^{ns}	0.986**	0.904*

•, *, **, *** and ns refer to the treatment effect being significant at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

Appendix 1c. Thousand seed weight (TSW) of wheat in 2004, canola in 2005, wheat in 2006 and canola in 2007 for termination method x termination time x N rate interaction in 2007 at Star City, Saskatchewan

Treatment			TSW (g)			
Termination						
Method	Time	N rate (kg ha^{-1})	2004 Wheat	2005 Canola	2006 Wheat	2007 Canola
			Method x Time x N Rate			
Herbicide	Cut 1	0	24.9	3.5	31.3	3.2
		40	27.6	3.5	32.2	3.0
		80	32.4	3.5	33.2	3.1
		120	32.1	3.4	33.2	3.2
	Cut 2	0	26.6	3.5	31.0	3.1
		40	29.2	3.6	32.0	3.0
		80	31.2	3.4	34.2	3.0
		120	32.0	3.5	34.3	3.2
	Spring	0	26.5	3.6	30.5	3.3
		40	27.3	3.6	32.2	3.1
		80	33.4	3.4	32.8	3.0
		120	32.6	3.5	33.5	3.2
Tillage	Cut 1	0	32.1	3.4	30.7	3.2
		40	32.0	3.4	32.1	3.1
		80	32.9	3.5	33.2	3.2
		120	32.5	3.5	32.8	3.2
	Cut 2	0	29.7	3.5	30.8	3.3
		40	33.7	3.5	32.0	3.1
		80	33.6	3.4	33.6	3.2
		120	33.5	3.4	33.4	3.3
	Spring	0	29.5	3.4	31.0	3.2
		40	30.3	3.4	32.7	317
		80	32.8	3.4	33.7	3.1
		120	34.3	3.4	33.4	3.2
Herbicide + Tillage	Cut 1	0	32.6	3.5	30.4	3.2
		40	33.2	3.5	31.9	2.9
		80	34.3	3.5	33.7	3.1
		120	34.4	3.5	32.9	3.2
	Cut 2	0	31.5	3.5	31.2	3.2
		40	31.5	3.5	31.6	3.1
		80	33.6	3.5	33.2	3.1
		120	33.4	3.5	33.7	3.3
	Spring	0	28.8	3.5	30.5	3.0
		40	29.3	3.5	32.4	3.0
		80	32.2	3.4	32.2	3.1
		120	33.1	3.5	32.2	3.1
		$LSD_{0.05}$	ns	ns	ns	ns
		SEM	0.90^{ns}	0.06^{ns}	0.48^{ns}	0.06^{ns}

^{ns} refers to the treatment effect being significant at $P \leq 0.10$ and not significant, respectively.

Appendix 2.

Appendix 2a. Effect of alfalfa termination method, termination time and N rate on bulk density of soil in the 0-5, 5-10, 10-15 and 15-20 cm depths in autumn 2007 at Star City in northeastern Saskatchewan

Treatment			Bulk density (Mg m^{-3}) in soil layers (cm)			
Termination						
Method	Time	N rate (kg ha^{-1})	0-5	5-10	10-15	15-20
				Method x Time x N Rate		
Herbicide	Cut 1	0	0.93	1.32	1.37	1.44
		80	1.06	1.32	1.43	1.53
	Cut 2	0	1.01	1.46	1.41	1.47
		80	1.01	1.32	1.41	1.43
	Spring	0	0.91	1.44	1.45	1.49
		80	1.03	1.26	1.40	1.44
Tillage	Cut 1	0	1.04	1.25	1.40	1.47
		80	0.93	1.18	1.33	1.42
	Cut 2	0	0.99	1.34	1.30	1.47
		80	1.12	1.30	1.42	1.48
	Spring	0	1.09	1.31	1.42	1.46
		80	1.00	1.18	1.42	1.46
		$LSD_{0.05}$	0.19	ns	0.09	0.10
		SEM	0.065$^{•}$	0.039^{ns}	0.032$^{•}$	0.036$^{•}$
				Method x Time		
Herbicide	Cut 1		1.00	1.32	1.40	1.48
	Cut 2		1.01	1.39	1.41	1.45
	Spring		0.97	1.35	1.43	1.46
Tillage	Cut 1		0.99	1.21	1.36	1.45
	Cut 2		1.05	1.32	1.36	1.48
	Spring		1.04	1.24	1.42	1.46
		$LSD_{0.05}$	ns	ns	ns	ns
		SEM	0.046^{ns}	0.027^{ns}	0.023^{ns}	0.025^{ns}

$^{•}$ and ns refer to the treatment effect being significant at $P \leq 0.10$ and not significant, respectively.

Appendix 2b. Effect of alfalfa termination method, termination time and N rate on bulk density of soil in the 0-5, 5-10, 10-15 and 15-20 cm depths in autumn 2007 at Star City in northeastern Saskatchewan

Treatment		Bulk density (Mg m^{-3}) in soil layers (cm)			
Method/Time	N Rate (kg N ha^{-1})	0-5	5-10	10-15	15-20
		Method X N rate			
Herbicide	0	0.95	1.41	1.41	1.47
	80	1.03	1.30	1.41	1.47
Tillage	0	1.04	1.30	1.37	1.47
	80	1.02	1.22	1.39	1.45
	$LSD_{0.05}$	ns	ns	ns	ns
	SEM	0.038^{ns}	0.022^{ns}	0.019^{ns}	0.021^{ns}
		Time X N rate			
Cut 1	0	0.99	1.28	1.39	1.46
	80	1.00	1.25	1.38	1.48
Cut 2	0	1.00	1.40	1.36	1.47
	80	1.06	1.31	1.41	1.46
Spring	0	1.00	1.38	1.44	1.48
	80	1.01	1.22	1.41	1.45
	$LSD_{0.05}$	ns	0.08	0.07	ns
	SEM	0.046^{ns}	0.027^{*}	0.023^{*}	0.025^{ns}
		Method			
Herbicide		0.99	1.35	1.42	1.47
Tillage		1.03	1.26	1.38	1.46
	$LSD_{0.05}$	ns	0.05	0.04	ns
	SEM	0.027^{ns}	0.016***	0.013^{*}	0.015^{ns}
		Time			
Cut 1		0.99	1.27	1.38	1.47
Cut 2		1.03	1.35	1.38	1.47
Spring		1.01	1.30	1.42	1.46
	$LSD_{0.05}$	ns	0.06	0.05	ns
	SEM	0.033^{ns}	0.019**	0.016^{*}	0.018^{ns}
		N rate			
	0	0.99	1.35	1.39	1.47
	80	1.03	1.26	1.40	1.46
	$LSD_{0.05}$	ns	0.05	ns	ns
	SEM	0.027^{ns}	0.016***	0.013^{ns}	0.015^{ns}

*, **, *** and ns refer to the treatment effect being significant at $P \leq 0.10$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

Appendix 3. Project action plan

Duration of Project: 2003-04, 2004-05, 2005-06, 2006-07, 2007-08 and 2008-09

Years Completed: 6 years

Funding Requested in 2008-09: As per contract

Action Plan:

April 2003 to March 2004

-Select a suitable site.
-Initiate the field experiment and establish treatments.
-Collect data on greenhouse gas emissions and soil mineral N.
-Complete annual report.

April 2004 to January 2008

-Collect data on greenhouse gas emissions.
-Fertilizer application, seeding, spraying and harvesting of plots, and collection, weighing, drying, grinding and analyses of soil and plant samples.
-Present trial at field tours whenever possible.
-Complete annual reports.

February 2008 to February 2009

- Complete all laboratory analyses on soil and plant samples.
-Calculations, tabulation and statistical analyses of data.
-Completion of interim and final reports, and if possible, write a technical and/or a scientific paper.